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Experimental study of structural behavior of mesh-box Gabion

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DEDICATION

We would like to dedicate this work to our families specially our Parents who loved and raised us, which we hope that they are Proud of us, for their sacrifice and endless support. We would like to dedicate it to our Martyrs, detainees and Wounded people who sacrificed for our freedom.

ACKNOWLEDGMENT

We would like to express our appreciation to our supervisor Dr. Osama Dawood for his valuable advices, continuous Encouragement, professional support and guidance. Hoping our research get the satisfaction of Allah and you as well.

ABSTRACT

The research described by the current dissertation was focused on studying the mechanical behavior of the wired-mesh gabions under axial compression load. And it is important to mention that there is no specific standard for using gabions as structural elements

It is a unique study because using this type of construction usually does not take into consideration the study of the structural behavior of these boxes, and here many of the problems facing the construction of this kind appears.

This research studied the behavior of these boxes through laboratory experiments. 18 samples of fixed boxes of dimensions 20 * 20 * 20 cm were exposed to axial load using unconfined compression machine. Two parameters were tested changing the diameter of steel bars and also the aggregate size diameter that were used in the design process of these boxes.

Stress-strain diagrams were monitored.

Results showed as the size of the aggregates is smaller, ultimate strength increased, modulus of elasticity increased

On the other hand, results showed that ultimate strength considerably increased increasing steel-bar diameter.

Furthermore, lab experiments showed that the behavior of the gabion is highly sensitive to manufacturing quality, It was found that in some cases the two boxes with the same specifications (steel bar diameter, aggregate size distribution) gave a different results due to the difference in manufacturing quality .

It was studied the vulnerability these cubes prone force and what is the influence of changing of steel bars diameter on the strength of the box, as well as the influence of the aggregate size on the strengthening of that box.

The labor experimental results indicate the deformation mode of a loaded gabion structure and the maximum stress that the box sustain.

ملخص البحث

ركز هذا البحث على دراسة الحالة الميكانيكة لمكعبات "الجابيون" تحت تأثير ضغط عمودي عليها بواسطة جهاز كسر المكعبات للوصول لاقصى قوة يتحملها المكعب الواحد , وهذه الدراسة مهمة حيث انه في جميع المنشات التي تم بناءها بواسطة الخبرة العملية ولا تعتمد على الحسابات الهندسسة.

دراسة الحالة الانشائية لصناديق "الجابيون"هي دراسة فريدة من نوعها نظرا لان معظم المستخدمين لهذا النوع من الانشاء لا يأخذون بعين الاعتبار دراسة السلوك الانشائي لهذه الصناديق , وهنا تظهر العديد من المشكلات التي تواجه المنشئات من مثل هذا النوع , لذلك يقوم هذا البحث على دراسة سلوك تلك الصناديق عبر التجربة المخبرية وذلك من خلال تعريض عينات من الصناديق ثابتة الابعاد 20*20*20 سم مع تغيير اقطار الحديد وايضا الركام المستخدم في عملية تصميم هذه الصناديق .

في هذا البحث تم مراقبة نتائج الاجهاد والتمدد الواقعة على المكعبات وقد اظهرت النتائج انه عند تقليل قطر الحصمة المستخدم وزيادة قطر الحديد فان قوة المكعب تزداد بشكل ملحوظ .

ومن اهم الحقائق التي تم استنتاجها من خلال التجربة العملية , قد تبين ان المصنعية تؤثر بشكل كبير على قوة الصندوق , حيث وجد ان مكعبين لهما نفس المواصفات " نفس قطر الحديد ونفس قطر الحصمة " اظهرا نتائج مختلفة , وهذا الاختلاف كان بسبب المصنعية المختلفة للصندوقين .

وبشكل عام فان البحث قائم على كسر صناديق الجابيون في جهاز كسر المكعبات الخرسانية للوصول الى اقصى قوة يتحملها الصندوق ومن ثم حساب الاجهاد الذي تعرض له , وايضا قمنا بربط ساعة قياس في الجهاز وذلك لكي نحصل على حجم التشوه الحاصل عند اقصى قوة يتعرض لها الصندوق لكي يتم حساب التمدد والاستطالة في الصندوق ككل , وفي النهاية تم الوصول الى ارقام وحقائق سيتم طرحها في هذا البحث.

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Abbreviation

MAS	**Maximum Aggregate Size**
HSLA	**High-strength, low-alloy**
MWFS	**Minimum Weight of Field Sample**
MWST	**Minimum Weight of Sample for Test**

CHAPTER ONE: INTRODUCTION

Chapter 1

1.1 Introduction

A gabion is derived from an Old Italian word, *gabion*, meaning "big cage", for erosion control, caged riprap is used for dams or in foundation construction.

Gabions are enclosures that can be filled with any sort of inorganic material: rock, brick, concrete debris or sometimes sand and soil, for use in civil engineering, road building and landscaping. The cages were originally wicker, but now are usually a welded mesh made of sturdy galvanized, coated, or stainless steel wire that won't bend when filled with rocks. In landscaping, gabion walls can support an earth wall, stabilize the soil, prevent erosion, and more.

History of gabion walls About 7,000 years ago, early gabion-type structures protected the banks of the Nile. In the medieval era, gabions were employed as military fortifications. Later they were used for structural purposes in architecture. Evidently, Leonardo da Vinci used gabion for the foundations of the San Marco Castle in Milan. In recent history, civil engineers have used gabions extensively to stabilize shorelines, riverbanks, highways, and slopes against erosion.

1.2 Problem statement

Since Gaza has gone through many wars that have left destruction and found a huge amount of construction debris in Gaza Strip and it is not usable.

Consequently the gabions help in getting rid of the construction debris, and it helps to clean up the environment as well as possible to be used in construction.

University of Palestine has been set up a Gabion project to reuse this rubble, the project was based on experience rather than the construction and engineering calculations, so many problems was found including deformations, rust and other ,without knowing the reasons.

Handicap international organization was setup a gabion Project at university of Palestine, this Project was construct a building using wire-mesh gabion for first time they used gabions the project face many structural problems However, no standards in designing boxes and they depended on random experimental way therefore No known behavior of the structural elements and Some deformations were noticed Cannot be explained.

This research will introduce the physical evidence

Accordingly the idea of the project come to us and we found that it must be use engineering ways to reduce these problems and to contribute to reach the best ways based on engineering calculations to avoid the dilemmas unknown reasons.

In case the obviously behave was identified of Gabion, we can modify the ways of using gabions to become more feasible and also help in identification the Design Method.

This research was focused on studying the mechanical behavior of gabions under axial load.

This study aims at describing the potential behavior of gabions as structural elements.

Figure 1.1: Handicap international project in university of palestine

1.3 Objectives

Study the structural behavior for Gabion under the impact of vertical and axial forces in order to reach the design coefficients for the using the gabions as elements of construction by:

1. To study the strength of gabions under different steel bar diameter.
2. To study the strength of gabions under different sizes of gravel.
3. To describe the mode of failure.
4. To monitor and study the stress-strain diagrams of different designs

1.4 Project layout

Chapter-1 Introduction and Problem Statement.
Chapter-2 Literature Review of the gabion construction.
Chapter-3 Methodology and the Experiment Program Used in the Study.
Chapter-4 Results and Analysis of the Experimental Work.
Chapter-5 Conclusions and Recommendations

CHAPTER TWO: LITERATURE RIVIEW

Chapter 2

2.1 General:

Gabion walls have been a civil engineer's building element for many years. Within their Primary use as erosion-prevention systems, dozens of papers and experiments have investigated the behavior of and possible improvements to the gabion wall system. Some of these investigations even include seismic behaviors—but all within the realm of use as A retaining system.

Though gabions have not been investigated as a construction option, the use of Adobe brick product has been. Adobe is used because it requires unskilled labor for Construction, and utilizes materials readily available in the immediate area, either Naturally-occurring (sand), or by purchase (cement), though these purchased materials are Very costly. However, this system has proven to be susceptible to moisture, making adobe.

A poor choice in the search for a system with greater longevity through rainy seasons (Chen, 2009). Gabion walls also present an initial investment for materials like wire Mesh, but have the capacity to last through multiple rainy seasons with minimal repairs, ideally.

This thesis investigates the possibility of a free-standing gabion wall system with Potential application to construction options. In researching literature dealing specifically with free-standing gabion wall systems, nothing appears to be in publication. The Purpose of this thesis, therefore, begins to fill in the voids in understanding free-standing Gabion wall behavior, more specifically, walls located in areas of mild seismicity.

2.2 Studying the Structural behavior of Gabions

In order to study mechanical characteristic of gabion meshes, engineering properties of reinforced gabion retaining wall and green reinforced gabion retaining wall, tests including air tensile tests of gabion meshes, fatigue and aseismic tests on gabion structures were carried out. The main tensile mechanical indexes of gabion meshes, fatigue property and seismic behavior of these two gabion structures were obtained. Test results showed: Air tensile curves of gabion mesh showed a zigzag shape; Main factors influencing the dynamic deformation behavior of gabion structures were amplitude of dynamic load, vibration times and so on, and vibration frequency had no significant influence; In fatigue tests, the maximum accumulated lateral deformation occurred in the third layer for reinforced gabion retaining wall, and the fifth layer for green reinforced gabion retaining wall.

2.3 Using Gabion for Engineering Application.

It was common to use gabion structure for the erosion protection of channel bed. Peyras et al. (1992) carried out one-fifth-scale model tests of stepped gabion spillways subjected to different types of water loads. The tests indicated for expected floods in excess of 1.5 m^3/sec/m the mesh and lacing must be strengthened whereas stepped gabion spillways can withstand flows up to 3 m^3/sec/m without great damage if setting of gabions complies with the code of practice. The tests also revealed some deformation of the gabions due to movements of the stone filling. Some advices were given by Les Ouvrages en gabions (1992) on preventing gabion deformation. It was indicated the stone quality and packing in the top layers and stone size (1.5 times larger than the mesh size) are crucial to the deformation of Gabion

In the design of erosion protection, gabion mattress was frequently used to resist the erosion of channel bed. Due to the similarity of shape, roughness, unit weight and connection method for each single gabion unit, the engineers are able to formulate a simple equation to describe the hydraulic characteristics of gabion structure. Stephen (1995) proposed a design procedure to determine the required average diameter of infilling stone and the thickness of gabion mattress to maintain the stability of the structure based on the engineering manual of U.S. Army Corps of Engineers (1991a) and guide specifications of U.S. Army Corps of Engineers (1991b). It was found that the stability of gabion mattress is much more dependent on the size of filling stone than on the thickness of mattress.

Agostini et al., 1987 and Gray and Sotir, 1996 indicated the advantage of using gabion structure in engineering practice. The main merit of gabion structures are their excellent function of free drainage and which alternately prevents the accumulation of excess pore water pressure and the associated instability problem. Moreover, the high porosity of gabion structure allows the flow infiltration and silt deposition in the pore space and this is advantageous to the invasion and growth of local plants and the conservation of ecosystem. The gabion structure is characterized by its monolithic and continuous construction process, reinforced structure, flexibility, permeability, durability, noise proofing, and beneficial environmental impact. Gabion structure is considered as an ecological structure, for it merges into the natural environment. The stone filling and the layer of vegetation growing on surface of the structure increase its landscape and durability. The wire mesh is zinc galvanized and polyvinylchloride coated to resist the corrosion.

At present in Taiwan the construction of gabion structures were mainly implemented for the revetment and retaining wall. Nevertheless, due to the particular hydrology condition and geography environment the gabion structures can be failed by the misuses in stream regulation and gully erosion control. Figures 2.1 and 2.2 illustrate the major applications of gabion structures.

(a)

(b)

Nan-Tou County (a) Zhu-Shan Township, Xiu Lin, Da-Hu-Di gabion retaining structure (b) Zhong-Liao, Qing-Shui village Roadside slope protection

Figure. 2.1: Gabion structures for retaining wall and slope protection in Taiwan

(a)Tao-Yuan County, Long-Tan, Nan-Keng creek

(b) Tai-Chung County, Tai-Ping City,
Tou-Bian-Keng creek
(with energy dissipation facility)

Figure 2.2: Gabion structure for stream regulation work in Taiwa

2.4 Gabion Retaining Wall

Gabions are mesh containers filled with small rocks. The rocks are too small to be used independently, but in steel mesh containers they form a strong material. Gabions are designed to protect soil around a stream or drain from erosion caused by running water. Stacking or terracing gabions creates a barrier between running water and soil. Gabions are produced in three forms: baskets, mattress and sack. Laying the mattress style on a gentle slope helps to protect the slope from soil erosion from water runoff. Stacked gabion baskets or sacks form a vertical wall or terrace structure Figure 2.3 show Gabion as Retaining Wall.

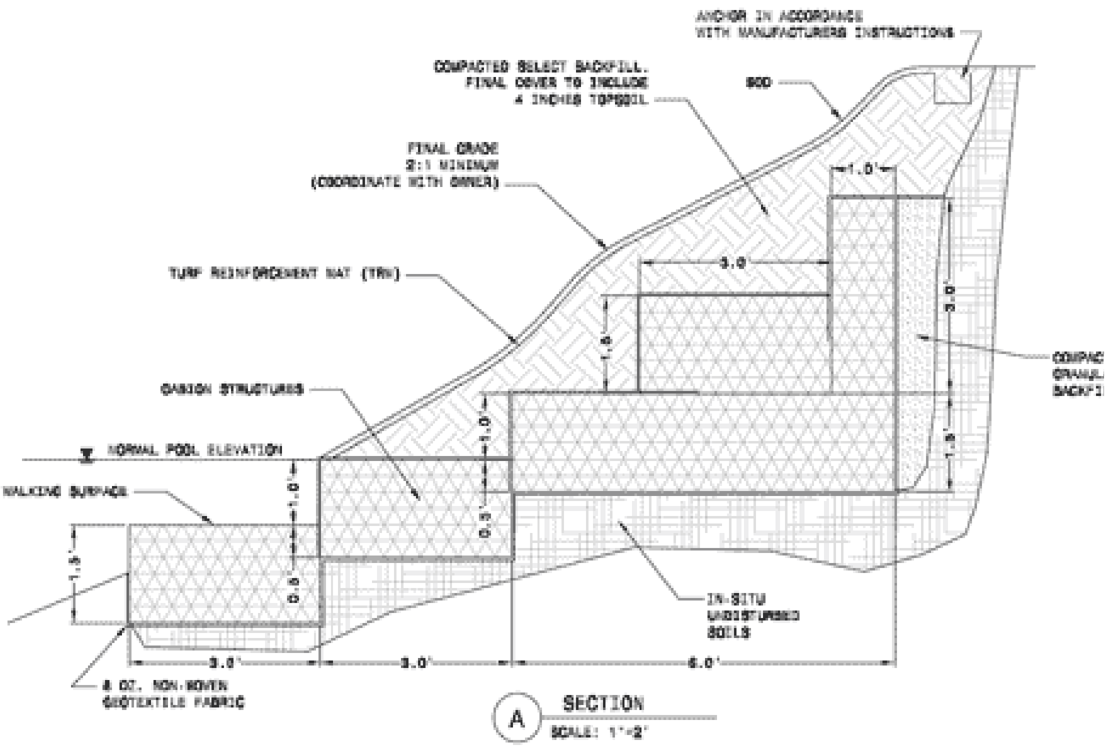
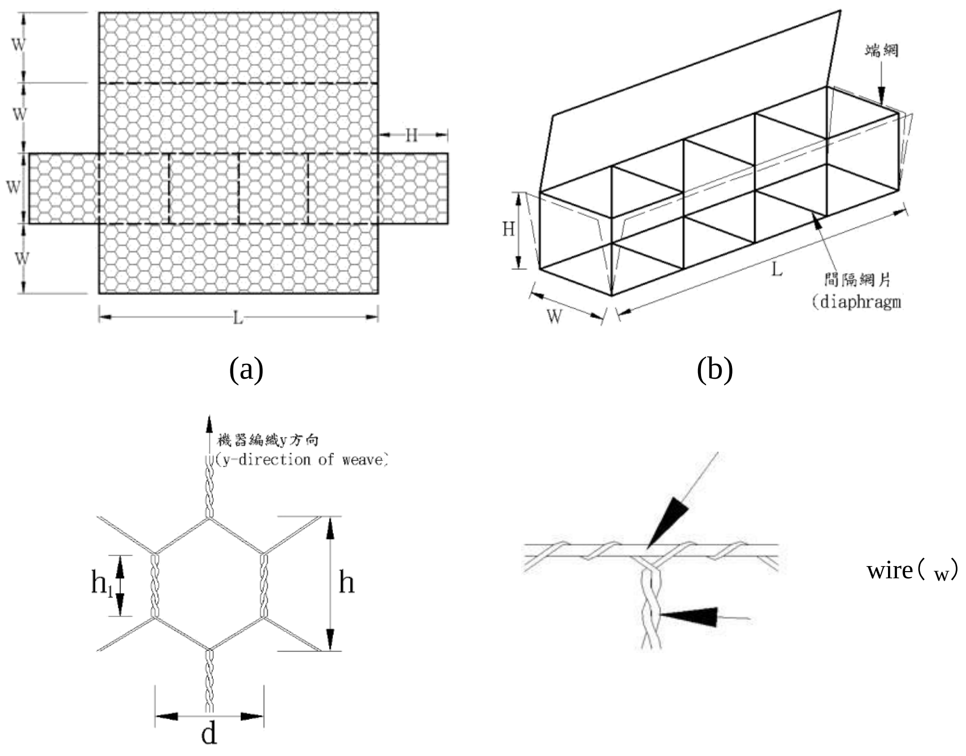


Figure 2.3: Gabion as Retaining Wall

2.5 MATERIAL PROPERTIES OF GABION STRUCTURES

2.5.1 Wire mesh of gabion

A remarkable study (DG Lin, YH Lin, FC Yu - INTERPRAEVENT 2010, 2010) .Investigated the deformation of gabion Structure in general, the wire used is soft steel and zinc galvanized to international standard. Zinc galvanized provides long term protection for steel wire against oxidation. The zinc galvanized wire is coated with special *PVC* (Polyvinylchloride) of 0.4~0.6 mm thick to give full protection against the corrosion from heavily polluted environment. The wire is woven into double twisted hexagonal wire mesh. At the construction site, the wire mesh of a single. Gabion unit with dimension of *W H L* (width height length) are opened and assembled as shown in Figure 2.4 (a) and (b). The single gabion unit can be subdivided into cells (with volume of 1 m^3 in general) by inserting diaphragms spaced 1 m from each other to strengthen the stiffness of structure and to facilitate its assembly. The opening of wire mesh and the lacing between frame and wire are illustrated in Figure 2.4 (c). Various dimensions of steel wire, wire mesh and gabion unit commonly used for gabion structure are summarized in Table 2.1.



(c)

Figure 2.4: Components of gabion unit (a) expansion of wire mesh (b) assembly of wire mesh (c) dimension of opening and lacing of frame and wire

Table 2.1: Dimensions of galvanized (zinc coated) wire and gabion unit (after foreign and Taiwan manufacturers)

Dimensions	Symbol	Unit	Specification
length	L	m	2.0/3.0/4.0/5.0
width	W	m	0.5/1.0/1.5/2.0
height	H	m	0.5/0.6/1.0/1.5
opening	$d\ h$	cm	5 8/8 10/10 15/15 20
twisted length	h_1	cm	4.5/6.0
diameter of wire	w	mm	1.8/2.7/3.0/3.5
diameter of frame	f	mm	3.0/3.5
thickness of *PVC* coating		mm	0.4～0.6

2.6 Design of Gabion

2.6.1 Wire mesh

Double twisted wire meshes made by mechanically twisting continuous pairs of wires (2.5mm dia.) and interconnecting them with adjacent wires to form square shape are used to make gabion boxes of various sizes. Materials used for the mesh shall be mild steel having a tensile strength of 350 MPa - 500 MPa and a minimum elongation of 10% at breaking load perfumed on a gauge length of 250 mm as per BS 1052: 1980. These wires shall be provided with coating of zinc and an additional coating of PVC.

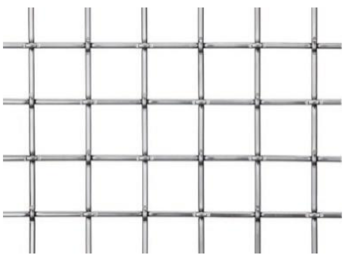


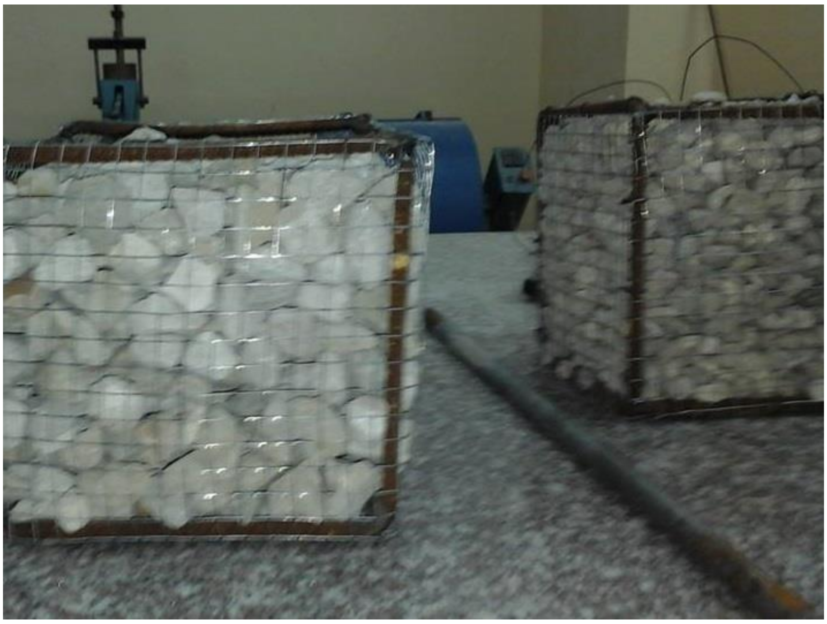
Figure 2.5: Wire mesh

Figure 2.6: Wire

According to BS 443: 1982. For welded mesh gabions, the panels of mesh which form the cages should be hot dip galvanized after welding according to BS 729: 1995 (this code has been recently replaced by BS EN ISO 3834 - 3: 2005).

The filler material shall be naturally occurring hard stones which are weather resistant, insoluble and of minimum size 1 to 2 times the dimension of the mesh. Stones with high specific gravity are preferable since gravity behavior of the structure is predominant.

The mesh dimensions for PVC coated galvanized gabion boxes are 100 x 100 mm.



Figure, 2.7 Gabion Box

2.6.2 Gabions

Gabion boxes are uniformly partitioned into internal cells using diaphragm walls, interconnected with similar units, and filled with stones at the project site to form flexible, permeable and monolithic structures such as retaining walls, sea walls, channel linings, revetments, facing elements for reinforced soil structures and weirs for erosion control purposes.

The gabions are manufactured in factories in sizes of .2*.2 m.

Individual empty units are connected the edges are then laced together by single and double twist lacing wires at 100 - 150 mm spacing. The first layer of gabion is seated on levelled flat surface and continuously secured together either by lacing or by tying the edges using fasteners. The end gabion is partly filled with suitable stones to form end anchor and there after bracing wires are fixed at 0.5 m spacing to avoid bulging of front side of gabion.

2.7 Gabion advantages

The gabion structures stand out as a simple, efficient and economical solution to various civil engineering construction problems due to the following advantages.

- Monolith city: The various elements in a gabion faced wall are linked through continuous fastening which ensures structural continuity. This allows regular distribution of the imposed forces and ensures that the whole weight of a structure
- Easy to repair any damaged boxes with minimum expense.
- Cost effective and suitable in all types of soil conditions.
- Work is simple and fast to execute.
- No need of shuttering and curing.
- Work is not affected by water shortage and on the other hand it is also not affected due to rains during monsoon.
- Cost savings is of the order ranging from 30% to 50%.
- Ecofriendly.
- Reduces sound pollution by absorbing sounds up to 18-28 db.
- Absorbs large vibrations and hence widely used near railway tracks.

Despite the fallacy that gabion structures are temporary works the reality is far different. Dry walls (stone walls) prove that gabion works may last for hundreds of years even if the wire netting rusts over a period of time. The double twist, in case of a break in any single wire, prevents the unraveling of the mesh and the movement of stones out of the gabion. Heavy zinc coating of wires assures that eventual deterioration of the netting by rusting is very slow under normal conditions. Where corrosion is a more severe problem, it is possible to considerably extend the wire life by making use of PVC coating. With the passage of time, gabion structures provide natural balances with the environment**.**

2.8 Gabion Disadvantages -

- Gabions are sometimes criticized as being unsightly. They can be made more attractive by use of attractive facing stone toward the front of the wall and by establishing vegetation in the spaces between the rocks.
- Low habitat value - On rivers and Estuary's - No wildlife burrowing and tunnels.
- The wire baskets used for gabions may be subject to heavy wear and tear due to wire abrasion by bedload movement in streams with high velocity flow.
- Can be labor intensive to fill large gabions by hand.
- Gabion walls in river and sea erosion control need to be immediately inspected and evaluated after any storm, which has caused heavier than normal water flow.

2.9 Planning Considerations:

For easy handling and shipping, gabions are supplied folded into a flat position and bundled together. Gabions are readily assembled by unfolding and binding together all vertical edges with lengths of connecting wire stitched around the vertical edges. The empty gabions are placed in position and wired to adjoining gabions. They are then filled with cobblestone-size rock (9.5 mm -3 cm diameter) to one-third their depth. Connecting wires, placed in each direction, brace opposing gabion walls together. The wires prevent the gabion baskets from "bulging" as they are filled. This operation is repeated until the gabion is filled. After filling, the top is folded shut and wired to the ends, sides, and diaphragms. During the filling operation live rooting plant species, such as willow, may be placed among the rocks. If this is done, some soil should be placed in the gabions with the branches, and the basal ends of the plants should extend well into the backfill area behind the gabion breast wall. Several different design configurations are possible with gabions. They may have either a battered (sloping) or a stepped-back front. The choice depends upon application, although the stepped-back type is generally easier to build when the wall is more than 10 feet high. If large rocks are readily accessible, inexpensive, and near the proposed site, then their use in construction of a rock wall may be preferable. On the other hand, if rock must be imported or is only available in small sizes, a gabion wall may be preferable.

2.10 Sequence of Construction:

Since gabions are used where erosion potential is high, construction must be sequenced so that they are put in place with the minimum possible delay. Disturbance of areas where gabions are to be placed should be undertaken only when final preparation and placement can follow immediately behind the initial disturbance.

2.11 Maintenance:

Gabions should be inspected on a regular basis and after every large storm event. All temporary and permanent erosion and sediment control practices shall be maintained and repaired as needed to assure continued performance of their intended function. All maintenance and repair shall be conducted in accordance with an approved manual.

CHAPTER THREE: METHODOLOGY

Chapter 3

3.1 Testing program

Number of tests have been conducted with different aggregate size and different steel bars. Figure 3.1 shows the flow chart of the testing programs.

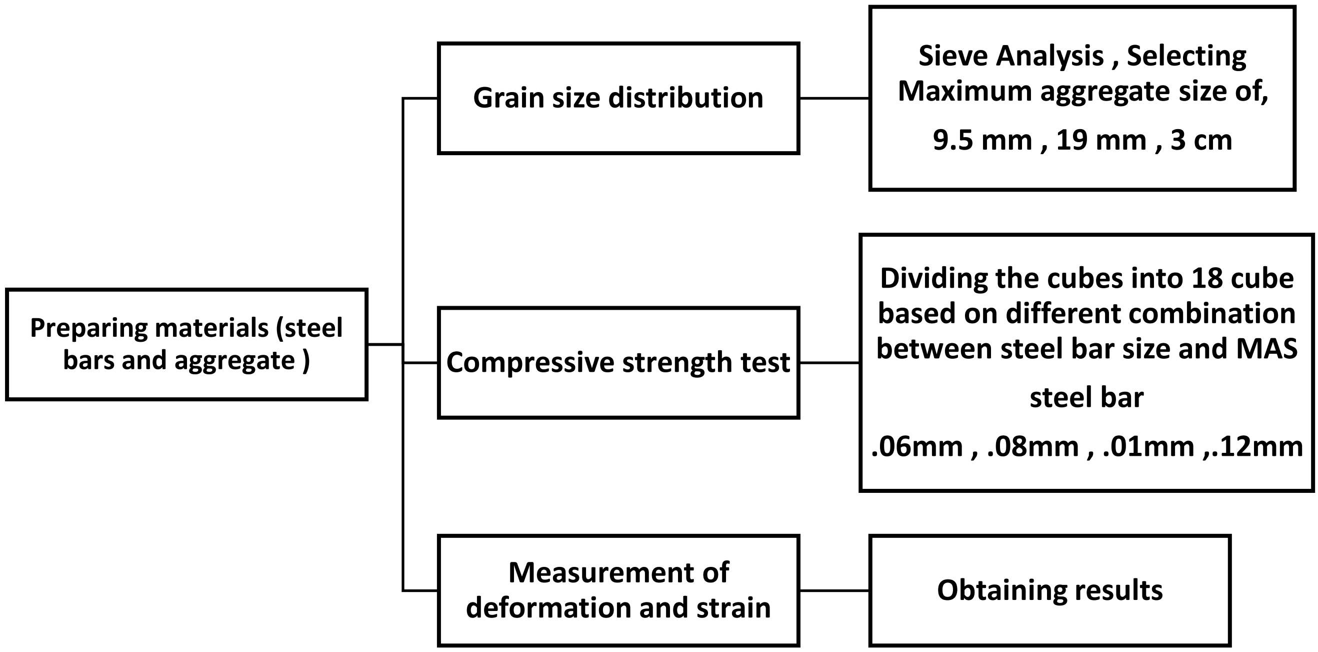


Figure 3.1: Testing program.

- **Testing program includes:**

3.1.1 Preparing materials (steel bars and Grain size distribution).

3.1.1.1 Steel

Steel is defined as an alloy of iron and carbon, though other alloying elements are also found in many steels. Perhaps the most dramatic property of steel is that some alloys can be strengthened by quench hardening. Red hot metal is rapidly cooled by plunging it into a liquid. These alloys can thus be ductile for fabrication and much stronger as a finished product. In our experiment we use steel bars with FY = 4200 kg/cm2., table 3.1 shows the bars diameter that we use to design the gabion boxes and the width to every one of them.

Table 3.1: bars diameter

SIZE (Diameter)	THEORETICAL WEIGHT KG/M	Cross-section Area Mm2
6 mm	0.222	30.69
8 mm	0.395	54.3
10 mm	0.62	85.2
12 mm	0.89	122.7

Figure 3.2: bars

Chemical properties of used Steel:

The primary types of structural steel are usually classified according to the following chemical composition categories:

- Carbon-manganese steels
- High-strength, low-alloy (HSLA) steels
- High-strength quenched and tempered alloy steel

Physical properties of used Steel:

Table 3.3 shows the Physical properties of used Steels

Table 3.2: Physical properties of steel

Items	METRIC UNITS
Specific Gravity	7.9
Density	7850 kg/m3
Melting Point	1300°C–1450°C
Bulk Modulus	159,000 MPa
Young's Modulus of Elasticity 2	207,000 MPa
Shear Modulus	83,000 MPa

Stress strain diagram:

Figure 3.3 shows the Stress strain diagram for the steel that we use to design the Gabion Boxes.

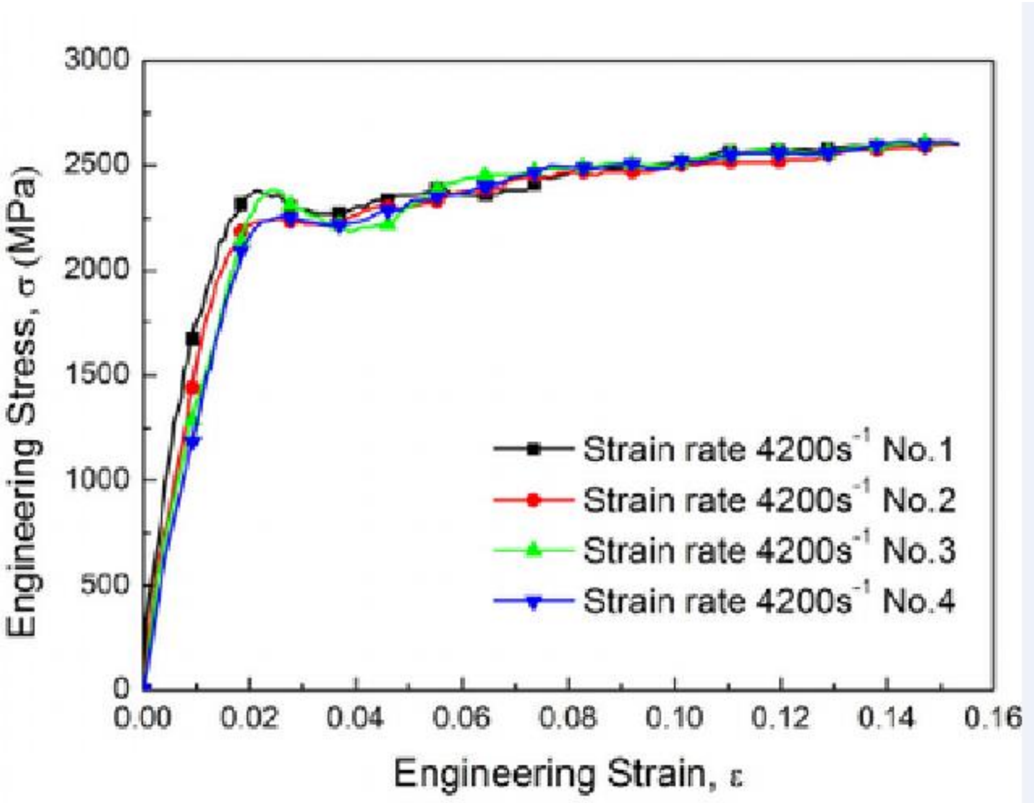


Figure 3.3: Stress strain diagram

3.1.1.2 Grain size distribution

Grain-size analysis, which is among the oldest of soil tests, is widely used in engineering classifications of soils.

Grain-size analysis is also utilized in part of the specifications of soil for airfields, roads, earth dams, and other soil embankment construction.

Additionally, frost acceptability of soils can be fairly accurately predicted from the results of grain-size analysis. The standard grain-size analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges.

Grain-size analysis of soils containing relatively large particles is accomplished using sieves.

A sieve is similar to a cook's flour sifter. It is an apparatus having openings of equal size and shape through which grains smaller than the size of the opening will pass, While larger grains are retained.

Obviously, a sieve can be used to separate soil grains in a sample into two groups: one containing grains smaller than the size of the sieve opening and the other containing larger grains.

By passing the sample downward through a series of sieves, each of decreasing size openings, the grains can be separated into several groups, each of which contains grains in a particular size range.

The various sieve sizes are usually specified and are standardized.

Soils with small grain sizes cannot generally be analyzed using sieves, because of the very small size of sieve opening that would be re quire and the difficulty of getting such small particles to pass through. See Figure 3.4 and Figure 3.5

A full set of sieves includes the following sizes [1]:

- 3 in. (75 mm)
- 2 in. (50 mm)
- 1½ in. (38.1 mm)
- 1 in. (25.0 mm)
- ¾ in. (19.0 mm)
- ⅜ in. (9.5 mm)
- No. 4 (4.75 mm)
- No. 10 (2.00 mm)
- No. 20 (0.850 mm)
- No. 40 (0.425 mm)
- No. 60 (0.250 mm)
- No. 140 (0.140 mm)
- No. 200 (0.075 mm)

Figure 3.4:Sieve analysis results

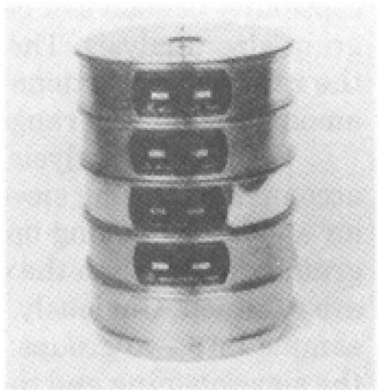


Figure 3.5: Sieves

Sieve analysis:

Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) – 1963.

In this we use different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves. Table 1 shows the Maximum Size of aggregates use in our experiment and MWFS, MWST.

Table 3.3: Maximum Size of Samples

Nominal Maximum Aggregate Size	Minimum Weight of Field Sample, g	Minimum Weight of Sample for Test, g
3/8 in. (9.5 mm)	4500	1000
3/4 in. (19.0 mm)	4500	2000
1.1811 in. (3 cm)	-	-

Natural aggregates types and definition:

- **Gravel**.—Granular material predominantly retained on the No. 4 (4.75-mm) sieve that results from natural disintegration and abrasion of rock or processing of weakly bound conglomerates.
- **Crushed grave**.—the product resulting from the artificial crushing of gravel or small cobblestones with substantially all fragments having at least one face resulting from fracture.
- **Crushed stone**.—The product resulting from the artificial crushing of rock, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation.
- **Sand**.—Granular material passing the 3/8-inch (9.5- mm) sieve, almost entirely passing the No. 4 (4.75-mm) sieve, and predominantly retained on the No. 200 (75-µm) sieve that results from natural disintegration and abrasion of rock or processing of completely friable sandstone.
- **Coarse aggregate**.—Aggregate predominantly retained on the No. 4 (4.75-mm) sieve (composed mainly of gravel-size particles).
- **Fine aggregate**.—Aggregate passing the 3/8-inch (9.5-mm) sieve, almost entirely passing the No. 4 (4.75- mm) sieve, and predominantly of sand-size particles).
- **Sand and gravel aggregate**.—A mixture (aggregation) of sand and gravel in which gravel makes up approximately 25 percent or more of the mixture.

Aggregate Used:

Natural aggregates: Crushed stone and gravel are the two main sources of natural aggregates. These materials are commonly used construction materials and frequently can be interchanged with one another. They are widely used throughout the United States, with every State except two producing crushed stone. Together they amount to about half the mining volume in the United States. Approximately 96 percent of sand and gravel and 77 percent of the crushed stone produced in the United States are used in the construction industry.

Figure 3.6: Aggregate Used:

3.2 Preparing the Boxes:

In order to prepare the gabion box following materials are needed:

Steel bars have been bending from 3 sides and the forth part was welded, and we have a bending steel bar, we made 2 faces of this and welded with 4 steel bar 20cm*20cm, as shown in Figure 3.7.

Wire mesh was formed by specifically form to suit the Box shape as shown in Figure 3.8.

Wire Was used to bind the Wire mesh into the steel bars by 3 links in each side as shown in Figure 3.9

Rubber was used to distribute the load on the steel bars and aggregate as shown in Figure 3.10

Figure 3.7: First face of box

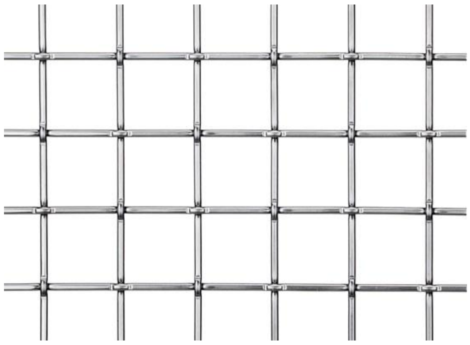


Figure 3.8: Wire mesh

Figure 3.9: Wire

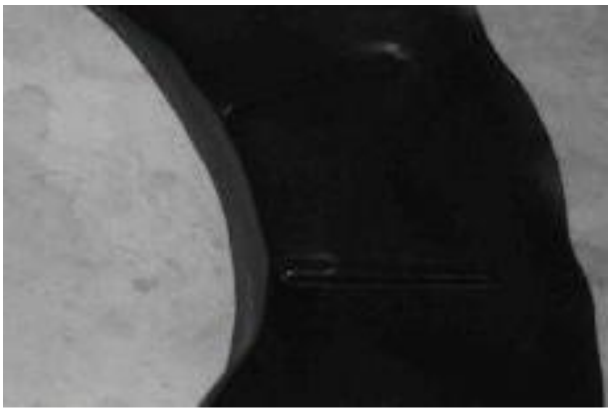


Figure 3.10: rubber

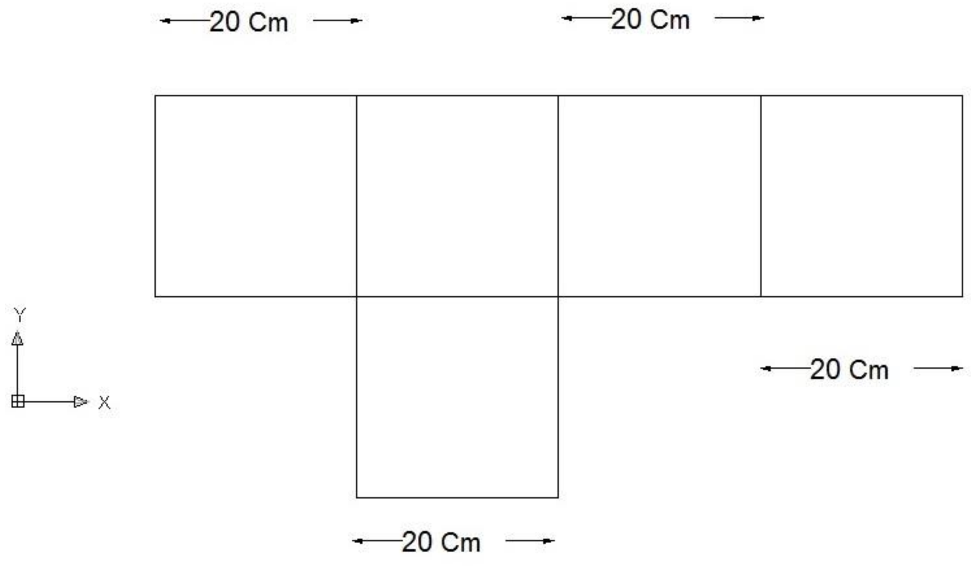


Figure 3.11: Wire mesh formation

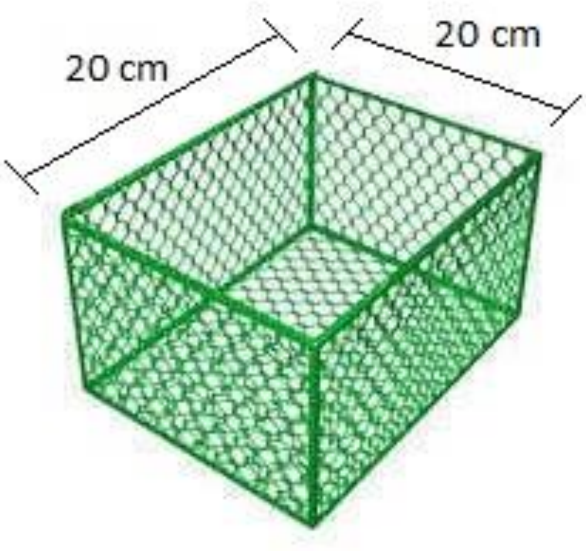


Figure 3.12: Final form of gabion Box

3.3 Test of Experiment:

3.3.1 Compressive Strength (for Gabion Boxes):

The specimens used in this compression test were 20× 20× 20mm Gabion Box three specimens were used in the compression strength test for every batch; this test was performed according to ASTM C39-04a.

And to guarantee that the load will be distributed to aggregate and steel bars we use rubbers above of the gabion box.

Figure 3.13: Compressive Strength machine

3.3.2 Deformation calculations

Determination of the change in length that have been produced by external forces and change in boxes as all.

The Compressive Strength machine dos not calculate the deformation, to overcome this obstacle we use a dial gauge.

We take the reading of the gauge every 5 seconds and recording the results. Figure 3.14 shows the diel gauge.

Figure 3.14: Dial gauge

3.3.3 Stress and strain Diagram

To determine the stress and the strain, stress = F/A, strain (ε) = ΔL/L

Where,

F = load from machine

A= Cross section area of the box (0.2*0.2) m.

L= length of the box.

By taking results from the compression strength machine and the dial gauge we use excel to draw the Stress and strain Diagram, and Figure 3.15 shows example of diagrams of stress and strain for our experiment.

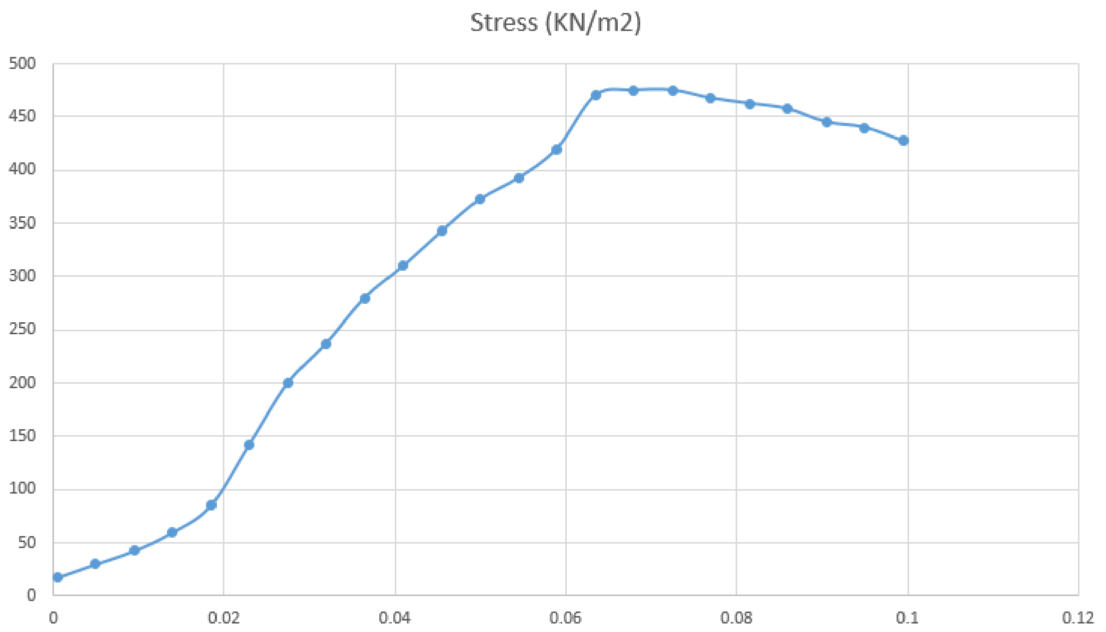


Figure 3.15: Example of Stress and strain Diagram for Gabion

3.4 All Experiment run

Using a different steel bar and different size aggregates, the table 5 shows all experiment gabion box that uses in experiment.

Table 3.4: All Experiment run

Steel Bar diameter	Diameter of gravel				
	9.5mm	*19mm*	*3cm*	*Empty*	
0.06 mm	-	1	1	1	
0.08 mm	**3**	**3**	**1**	**2**	
0.1 mm	**-**	**1**	**1**	**1**	
0.12 mm	**-**	**1**	**1**	**1**	
Total	**3**	**6**	**4**	**5**	**18 Box**

3.4.1 Procedure of experiment:

Compressive strength test experiment includes several steps to reach the final results:

1. Preparing all boxes as that shown in Table 3.4.
2. Filling the boxes by different aggregate size as Figure 3.16.
3. Installing and fixing dial gauge as Figure 3.17.
4. Placing the rubber on the top of box.
5. Placing the gabion box into compaction machine figure as Figure 3.18.
6. Compressing the gabion box.
7. Taking the measurements of load and dial gauge.
8. Recording the data to analysis after that.

For more photos of work see appendix A


Figure 3.16: Filling the boxes


Figure 3.17: Install dial gauge


Figure 3.18: compaction machine

CHAPTER FOUR: RESULTS AND ANALYSIS

Chapter 4

4.1 Gabion Samples testing

4.1.1 Introduction

As discussed in the chapter "3" Several gabion boxes Samples were prepared at different variables.

Several gabion boxes Samples were prepared at different variables. **Table 4.1** shows number of samples used with the different variables.

Table 4.1: Number of samples

Box No.	*Aggregate Size*	*Steel bar Diameter*
1	19 mm	Φ.08
2	9.5 mm	Φ.08
3	9.5 mm	Φ.08
4	9.5 mm	Φ.08
5	19 mm	Φ.08
6	19 mm	Φ.10
7	3 cm	Φ.08
8	19.5	Φ.12
9	3 cm	Φ.12
10	19mm	Φ.06
11	3 cm	Φ.06
12	19 mm	Φ.08
13	3cm	Φ.10

4.1.2 Samples results :

Compressive strength test shows the results for load and deformation that impact on boxes, and by equations the stress strain diagram was establish for all of boxes.

After compressing the boxes and deduced the results as shown below, a relationship has been established and Stress Strain Diagram was constructed for gabion boxes.

Table 4.2, Table 4.3 and Table 4.4 shows the results of sample boxes.

Figure 4.1, Figure 4.2 and Figure 4.3 shows the stress strain diagram of sample boxes.

Table 4.2: stress strain values of box No.(3)

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.7	0.1	0.0005	17.5
1.2	1	0.005	30
1.7	1.9	0.0095	42.5
2.4	2.8	0.014	60
3.4	3.7	0.0185	85
5.7	4.6	0.023	142.5
8	5.5	0.0275	200
9.5	6.4	0.032	237.5
11.2	7.3	0.0365	280
12.4	8.2	0.041	310
13.7	9.1	0.0455	342.5
14.9	10	0.05	372.5
15.7	10.9	0.0545	392.5
16.8	11.8	0.059	420
18.8	12.7	0.0635	470
19	13.6	0.068	475
19	14.5	0.0725	475
18.7	15.4	0.077	467.5
18.5	16.3	0.0815	462.5
18.3	17.2	0.086	457.5
17.8	18.1	0.0905	445
17.6	19	0.095	440
17.1	19.9	0.0995	427.5

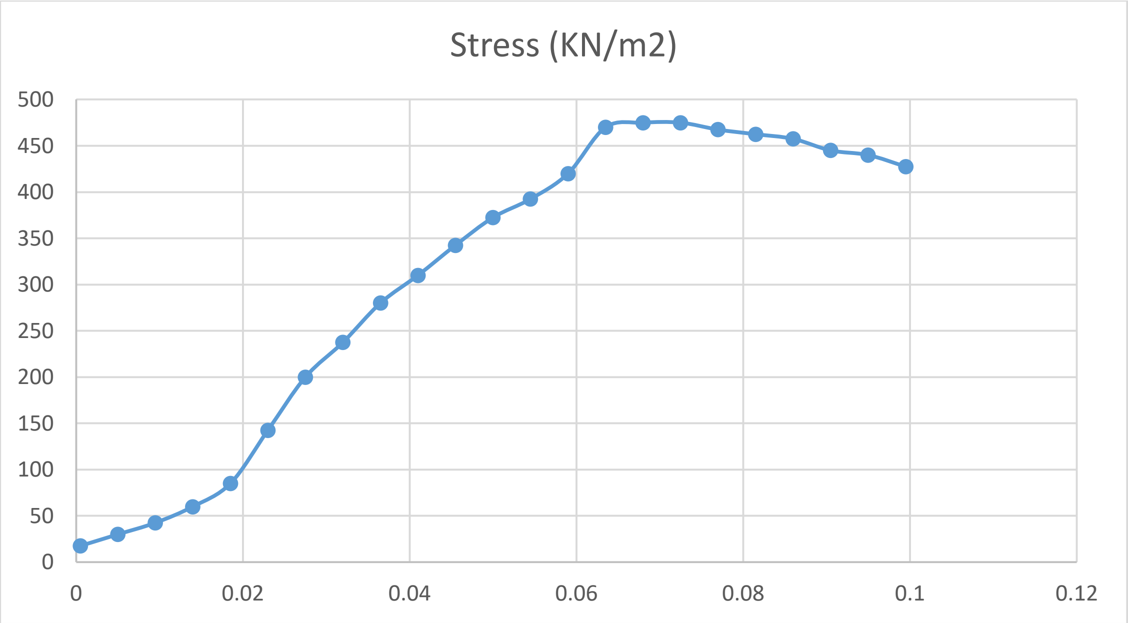


Figure 4.1: stress strain diagram of box No. 3

Table 4.3: stress strain values of box No. (1)

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.6	0	0	15
1.1	0.9	0.0045	27.5
1.2	1.8	0.009	30
2	2.8	0.014	50
2.3	3.9	0.0195	57.5
3	5	0.025	75
4.1	6.1	0.0305	102.5
5.5	7.2	0.036	137.5
7	8.3	0.0415	175
8.6	9.4	0.047	215
10.9	10.5	0.0525	272.5
13.4	11.6	0.058	335
16.4	12.7	0.0635	410
20.3	13.8	0.069	507.5
21.4	14.9	0.0745	535
23.2	16	0.08	580
26	17.1	0.0855	650
26.1	18.2	0.091	652.5
25.3	19.3	0.0965	632.5
24.7	20.4	0.102	617.5
24	21.5	0.1075	600
23.5	22.6	0.113	587.5
23	23.7	0.1185	575

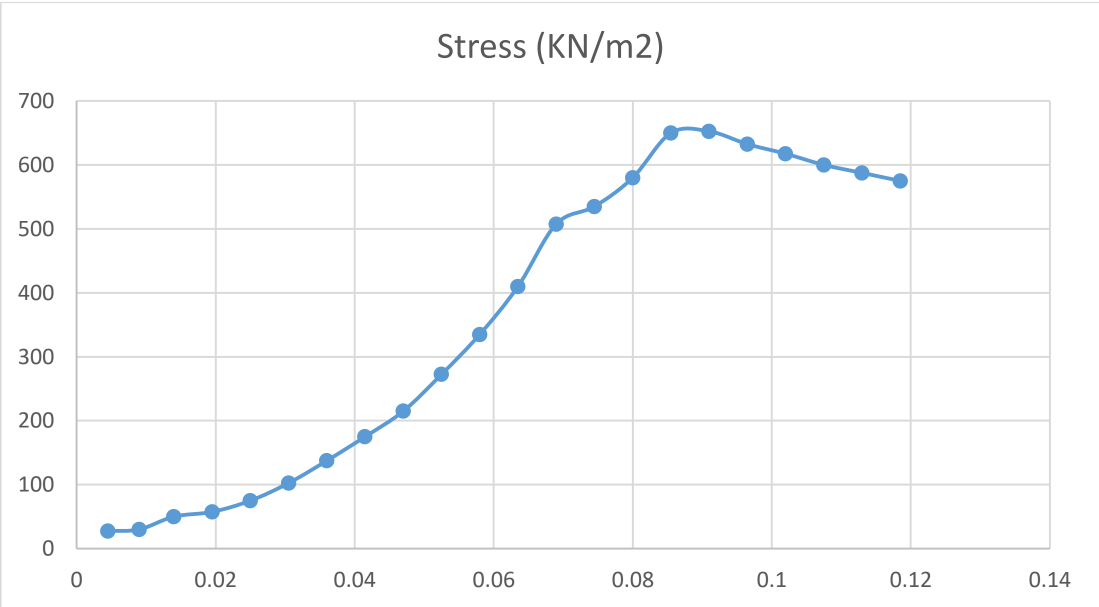


Figure 4.2: stress strain diagram of box No. 1

Table 4.4: stress strain values of box No. (2)

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.8	0	0	20
1	0.11	0.00055	25
1.4	1.1	0.0055	35
2.1	2.1	0.0105	52.5
3	3.1	0.0155	75
5.1	4.1	0.0205	127.5
8.4	5.1	0.0255	210
12.7	6.1	0.0305	317.5
15.5	7.1	0.0355	387.5
17.4	8.1	0.0405	435
19.4	9.1	0.0455	485
21	10.1	0.0505	525
21.6	11.1	0.0555	540
23.3	12.1	0.0605	582.5
25.3	13.1	0.0655	632.5
27.2	14.1	0.0705	680
27.7	15.1	0.0755	692.5
25.6	16.1	0.0805	640
25.1	17.1	0.0855	627.5
24.6	18.1	0.0905	615
23.8	19.1	0.0955	595
23	20.1	0.1005	575
22.1	21.1	0.1055	552.5

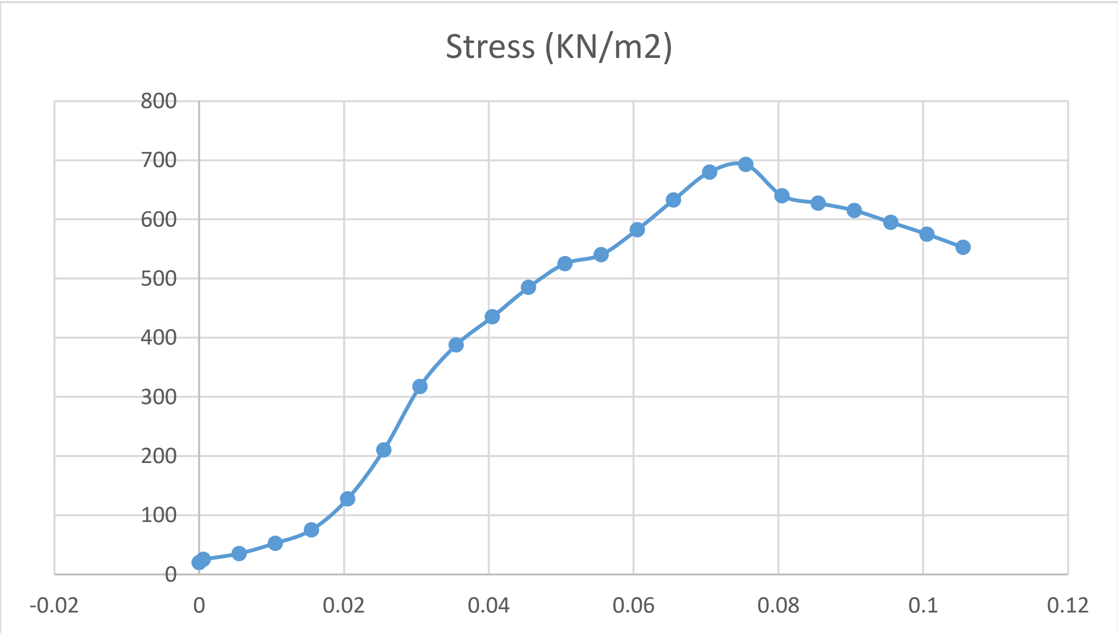


Figure 4.3: stress strain diagram of box No. 2

For results of all Boxes see appendix B

Figure 4.4 shows the different mark points on the stress and strain diagram of Box number (3) as an example.

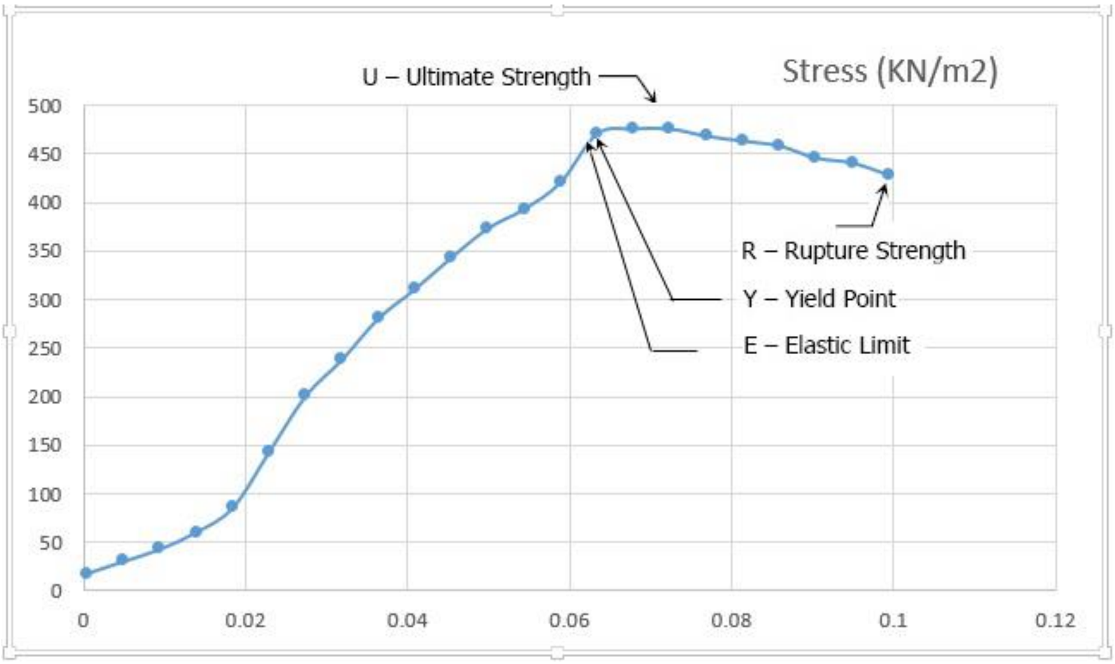


Figure 4.4: different mark points on the stress and strain diagram

As it is shown in Figure 4.4 observing that the boxes passing through many phases, These phases are:

1. Elastic Limit.
2. Yield Point.
3. Ultimate Stress Point.

And the rupture point in boxes Considered the failure phase that the boxes reach to yielding stress in it, and after that the deformation increases by the same (or lower) stress.

From the diagram one can see the different mark points on the curve. It is because, when a ductile material like mild steel is subjected to compression test, then it passes various phases before fracture.

- **Elastic limit**

Elastic limit is the limiting value of stress up to which the material is perfectly elastic. From the curve, point E is the elastic limit point. Material will return back to its original position, if it is unloaded before the crossing of point E. This is so, because material is perfectly elastic up to point E.

- **Yield stress point**

Yield stress is defined as the stress after which material extension takes place more quickly with no or little increase in load. Point Y is the yield point on the graph and stress associated with this point is known as yield stress.

- **Ultimate stress point**

Ultimate stress point is the maximum strength that material have to bear stress before breaking. It can also be defined as the ultimate stress corresponding to the peak point on the stress strain graph. On the graph point U is the ultimate stress point. After point U material have very minute or zero strength to face further stress.

- **Breaking stress (Rupture point)**

Breaking point or breaking stress is point where strength of material breaks. The stress associates with this point known as breaking strength or rupture strength. On the stress strain curve, point B is the breaking stress point.

4.2 Compressive Strength Test:

Compressive strength of boxes can be defined as the measured of maximum resistance of gabion boxes to axial loading. Compression test is commonly used to find the compressive strength of hardened boxes specimens.

The strength of the gabion boxes specimens with different Variables like steel bars diameter, and aggregate size, as shown in Table 3.4.

This test was performed by using concrete compressive strength machine.

4.3 Comparison of results:

The comparison between the results basis on the change in the aggregate size and change of the steel bars diameter, Therefore the studied was on the effect of the size of aggregates with same steel bars diameter, also studied the effect of changing steel bars diameter with same size of aggregates, and conducted a study to shape deformation and stress for empty boxes in order to getting the best results.

4.3.1 Influence of changing aggregate size:

Tests on the gabion boxes that have the same steel diameter with the change of aggregate size. Table 4.5 shows the sample of boxes that have a same steel bar diameter and different aggregate size.

Table 4.5: sample of boxes

Box No.	***Aggregate Size***	***Steel bar Dia.***
1	19 mm	Φ.08
2	9.5 mm	Φ.08
7	3 cm	Φ.08

Figure 4.5, shows the stress and strain diagram for all Boxes No. 1

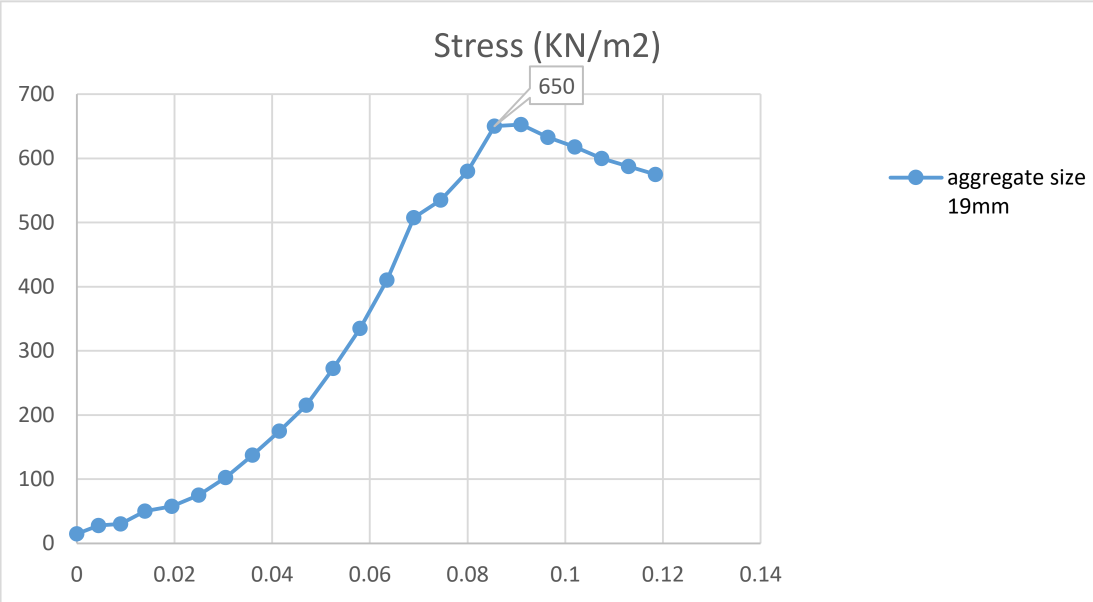


Figure 4.5: stress and strain diagram for Box No. 1

Figure 4.6, shows the stress and strain diagram for Box No. 2

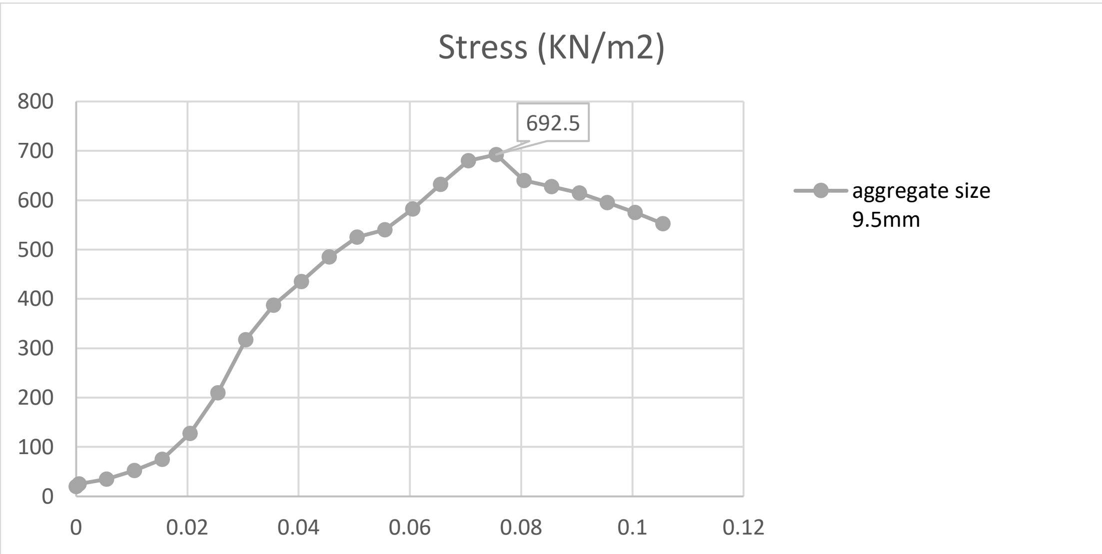


Figure 4.6: stress and strain diagram for Box No. 2

Figure 4.7, shows the stress and strain diagram for all Boxes No. 7

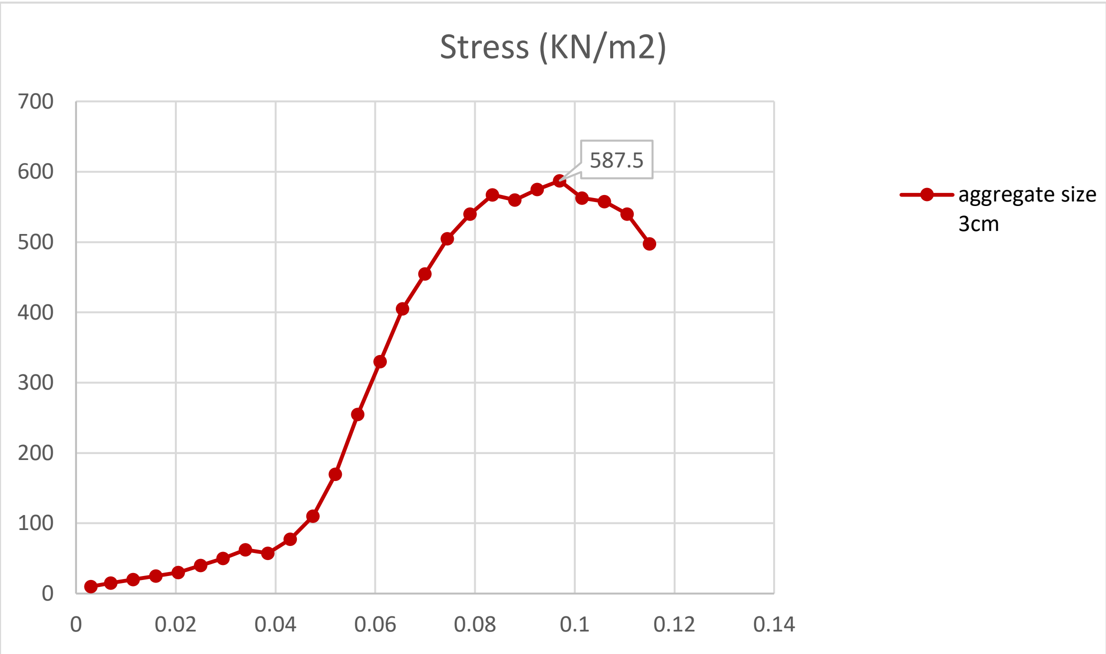


Figure 4.7: shows the stress and strain diagram for Box No. 2

Figure 4.8, shows the stress and strain diagram for all Boxes that have the same steel bar and different size aggregate.

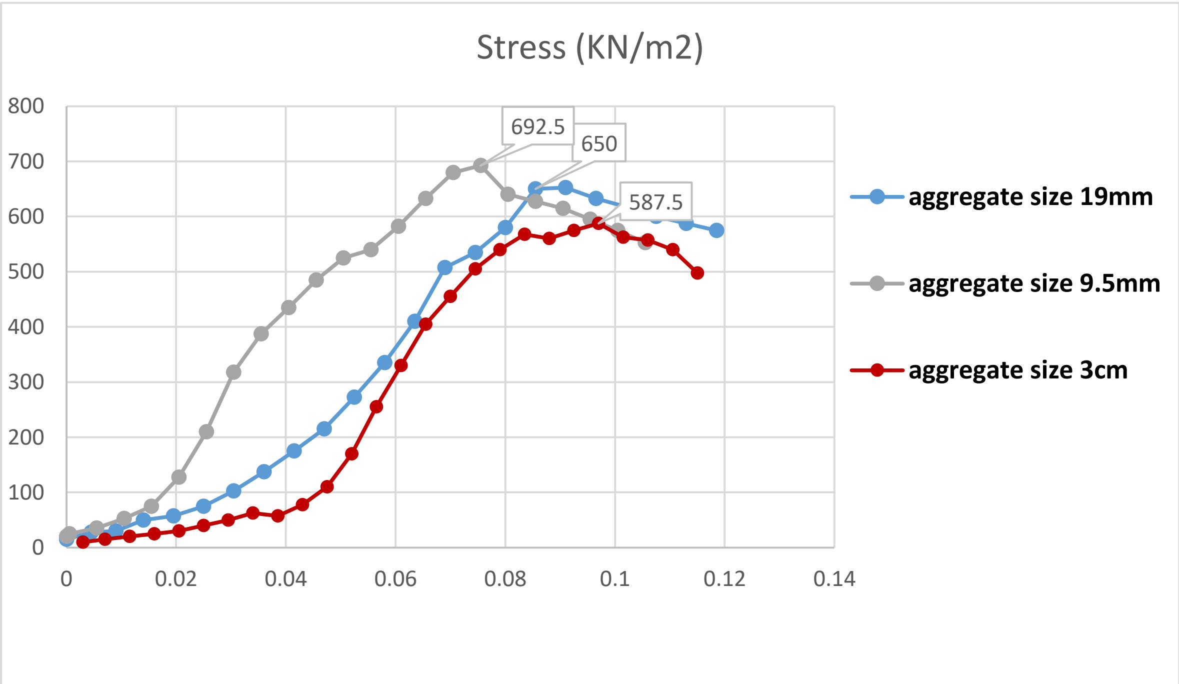


Figure 4.8: stress strain diagram for all Boxes

After showing all results when aggregate size change the following notes can be pointed out:

1. Box No. (2) with the least aggregate size has the highest Stress =692.5 KN/m2.
2. Box number (7) with the greatest aggregate size (3 cm) has the least stress 587.5 KN/m2.

It is noted that every time that we increase aggregate size the stress decreases.

It is possible that the differences in results emerged from problems in manufacturing quality. However, the UCS test usually involves high uncertainty even in more homogeneous materials such as concrete.

4.3.2 Influence of changing steel bars :

Tests on the gabion boxes that have the same aggregate size with the change of steel diameter.

Table 4.4 shows the sample of boxes that have the same aggregate size with the change of steel diameter.

Table 4.6: sample of boxes

Box No.	***Aggregate Size***	***Steel bar Dia.***
6	19 mm	Φ.10
8	19 mm	Φ.12
10	19 mm	Φ.06
12	19 mm	Φ.08

Figure 4.9, shows the stress and strain diagram for all Boxes No. 6

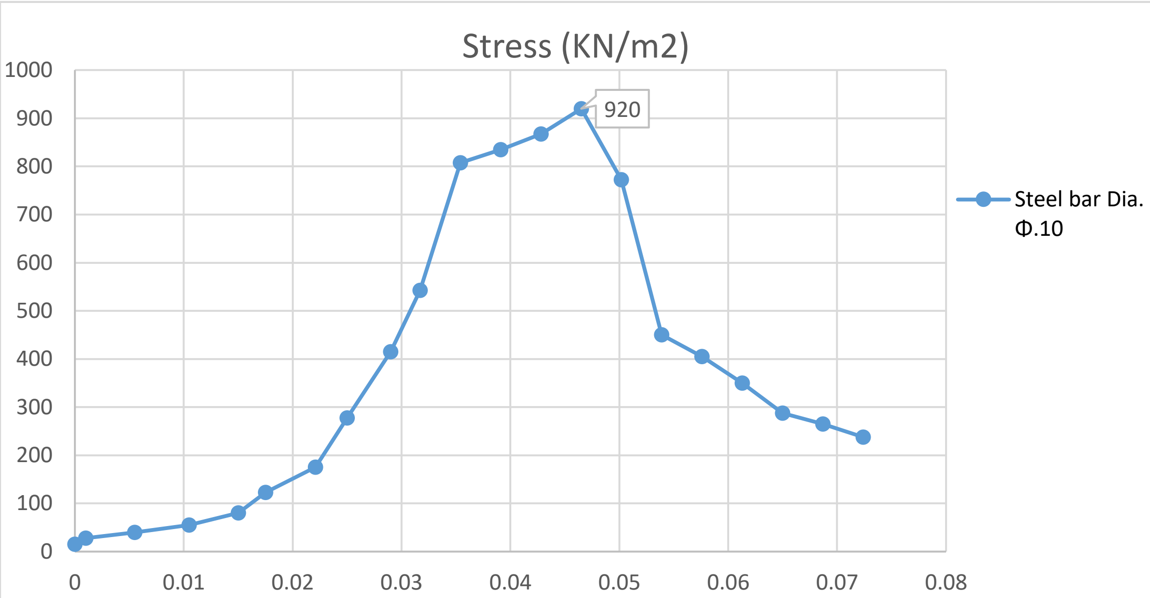


Figure 4.9: stress and strain diagram for Box No. 6

Figure 4.10, shows the stress and strain diagram for Box No. 8.

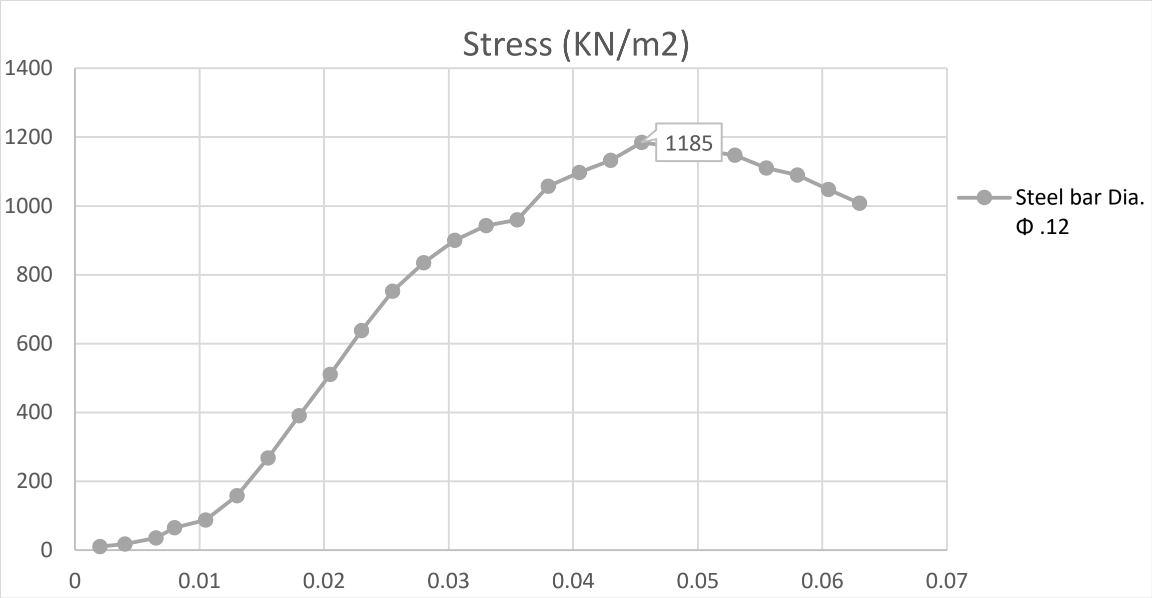


Figure 4.10: stress and strain diagram for Box No. 8

Figure 4.11, shows the stress and strain diagram for all Boxes No. 10

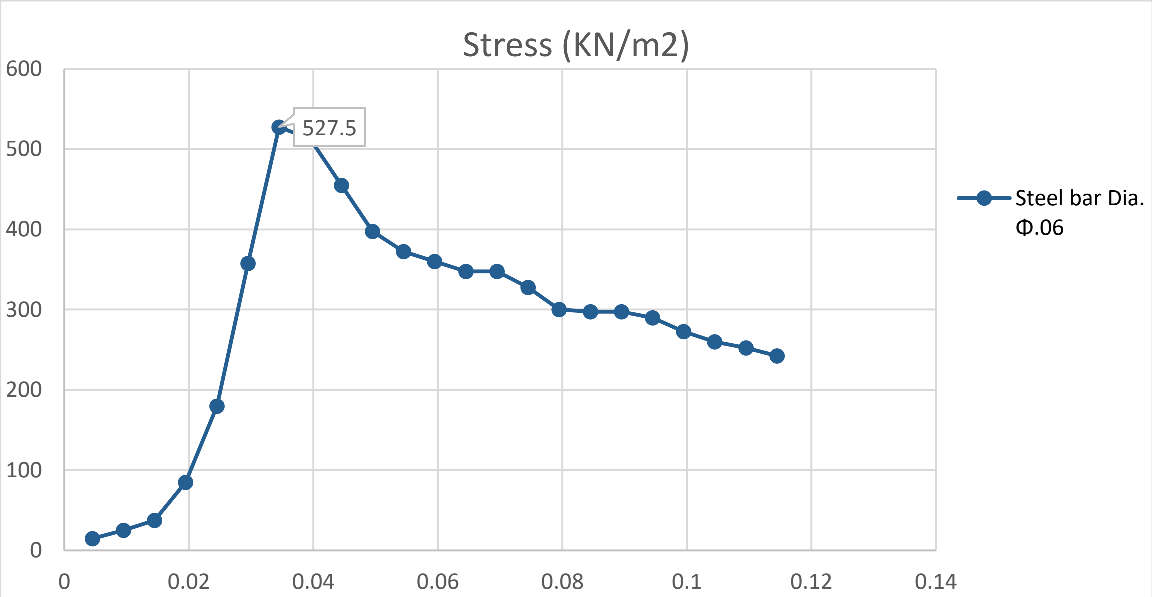


Figure 4.11: shows the stress and strain diagram for Box No. 10

Figure 4.12, shows the stress and strain diagram for all Boxes No. 12

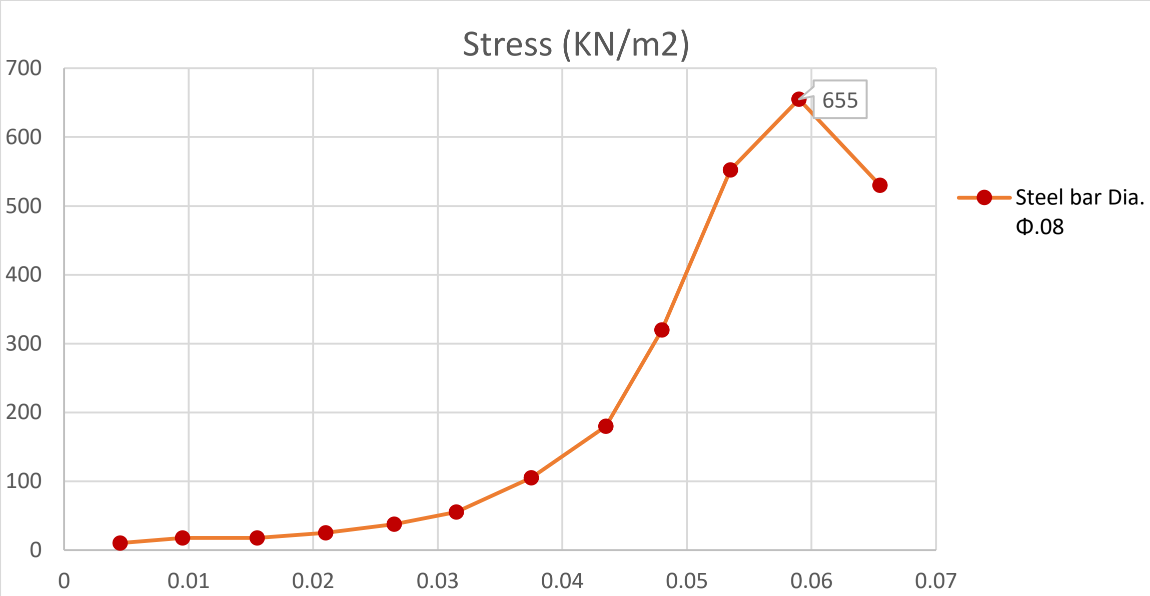


Figure 4.12: shows the stress and strain diagram for Box No. 12

Figure 4.13, shows the stress and strain diagram for all Boxes that have the same size aggregate and different steel bar.

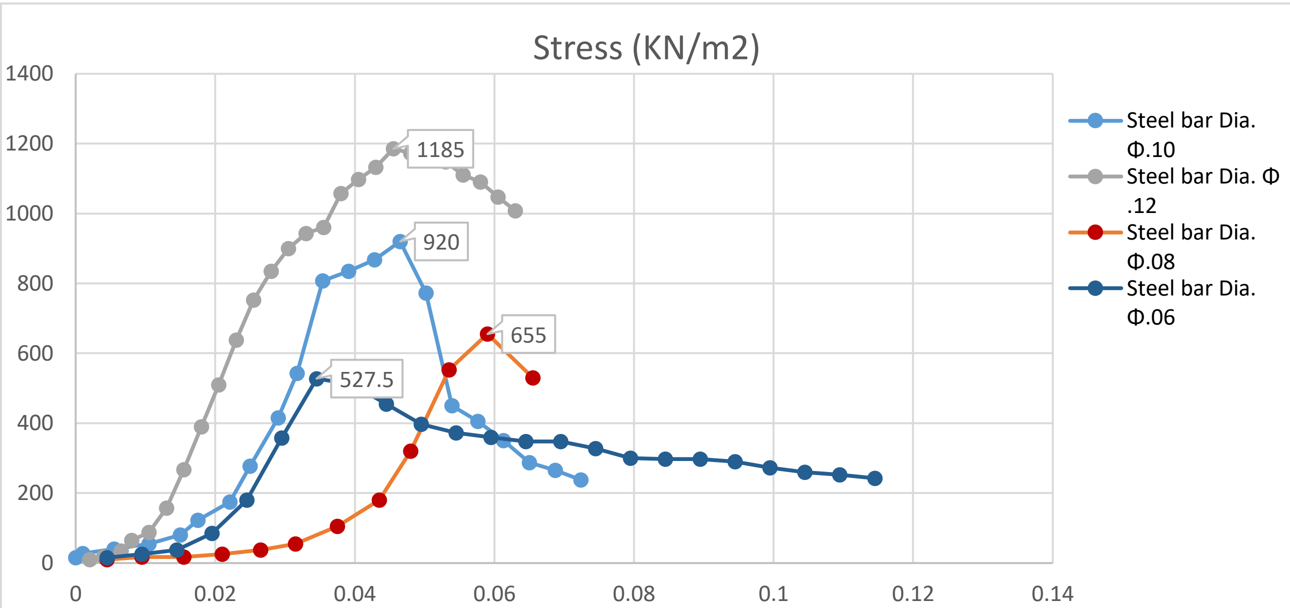


Figure 4.13: stress strain diagram for all Boxes

After showing all results when the steel bar was change the following notes can be pointed out:

1. Box number (8) with the greatest steel bar diameter “Φ.12” has the highest Stress =1185KN/m2. This box examined a problem during the test that

might postponed the measurements of deformation. However, the measured ultimate strength was fine.

2. Box number (10) with the least steel bar diameter "Φ.06" has the least stress 527.5 KN/m2.

It is noted that every time that we increase the steel bar diameter the stress will increase, and when the steel bar diameter decrease the stress will decrease.

For results of each boxes separately see appendix B

CHAPTER FIVE: CONCLUSIONS AND RECOMMEDNATIONS

Chapter 5

5.1 Conclusions:

Gabion is a structural element mainly used in walls that resisting lateral earth pressure, it is a permeable element composed of steel bars, natural aggregate and wire mesh, It is also designed to sustain vertical load usually its own weight, Throughout this research, we have investigated the mechanical behavior of gabion structural boxes under the vertical load represented as compressive strength.

Gabions showed strength that ranged from **1185 KN/m2 to 527.5 KN/m2**, which varied according to diameters and steel bars.

The following conclusions were drawn according to the results acquired by this research:

- The results showed a high influence of steel bar diameter on the strength of the gabions. This matches the outcomes from previous study which reported that the load is mainly transferred to the steel bars rather than the soil aggregates. The study showed that the stresses that transferred to the steel are two orders of magnitude greater of the stresses transferred to the aggregates.
- The results showed that smaller aggregate sizes resulted in higher strength. This could be explained on the bases of the potential surfaces that resist friction between soil particles. This increases the paths of stress transfer to the soil and then to the base of the box. At the same time, it mitigates the stress that transfers to each grain of the aggregates. Moreover, the transfer of the loads to the side walls of the mesh box becomes more concentrated in the case of large particles. This increases the potential for failure.
- In addition, the mode of failure that was typically noticed shows that steel bars bend outwards. However, many boxes showed different modes of failure. The visual investigation suggests that the failure is related to the manufacturing quality of the boxes. This suggests that the modes of failure of mesh-box gabions is sensitive to the manufacturing defects.
- The elasticity of the samples were noticed to be almost of the same magnitude. This remarkable noticed could be explained on the basis of the fact that the load

is basically transferred to the steel bars. This suggests that the elasticity of the boxes was governed by the elasticity of the steel, which was the same for all samples.

- Furthermore, it is important to mention that a research has been conducted in the same university ;(Swati et al 2016 studying structural behavior of steel mesh box gabion using numerical modeling), the research discussed the same topic of gabion compression but using software, the output was approximately running in the same trend of this research.

5.2 Recommendation

The following recommendations can be pointed out:

- Better control of compressive strength and strain test is recommended.
- Studies on the effects of lateral pressure on gabion needed to be investigated.
- This test was limited to gabions of 20x20x20. Further studies that investigates the influence of gabion boxes size is recommended.
- Checking the influence of wire mesh in strength of gabion box.
- Since the control of the gabion strength is the steel bars, investigation of other materials instead of natural aggregate is recommended. This might include plastic, wood, or any other green material.
- The durability of the gabions is recommended to be studied.

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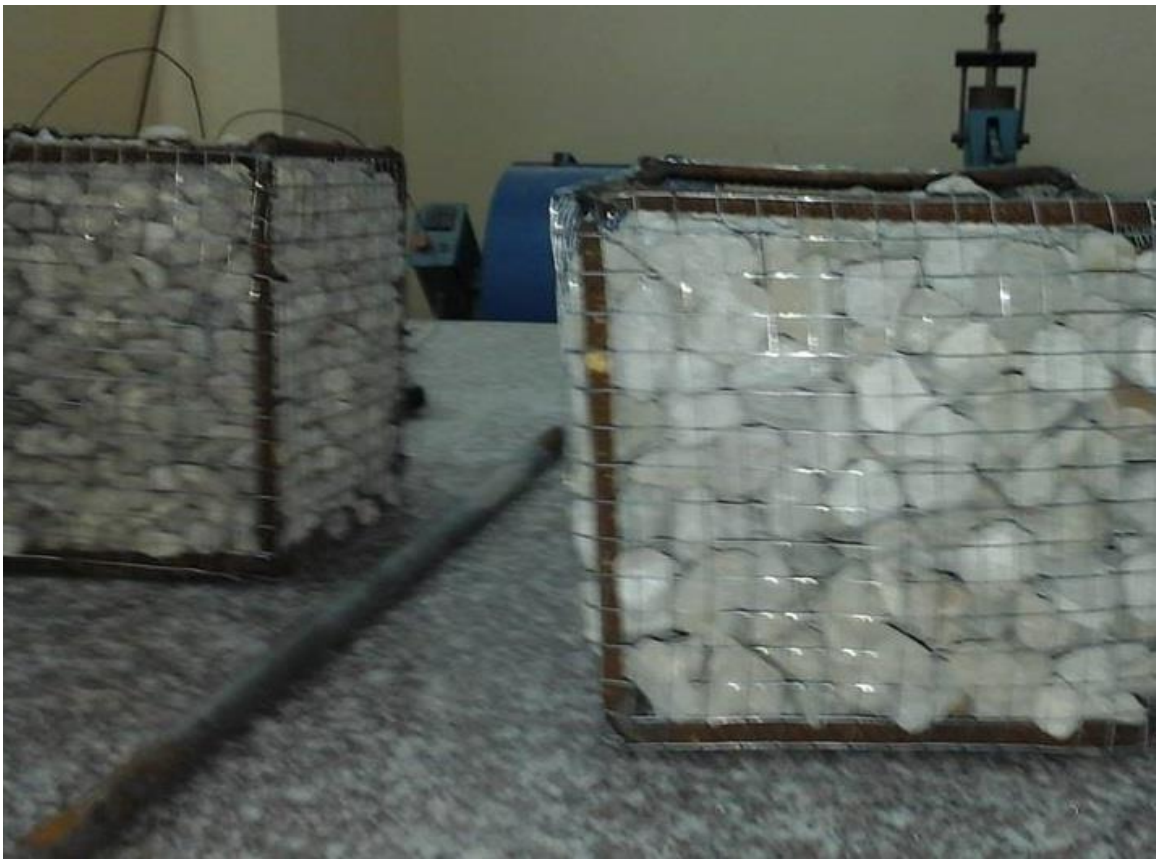
Appendix A: Research photo



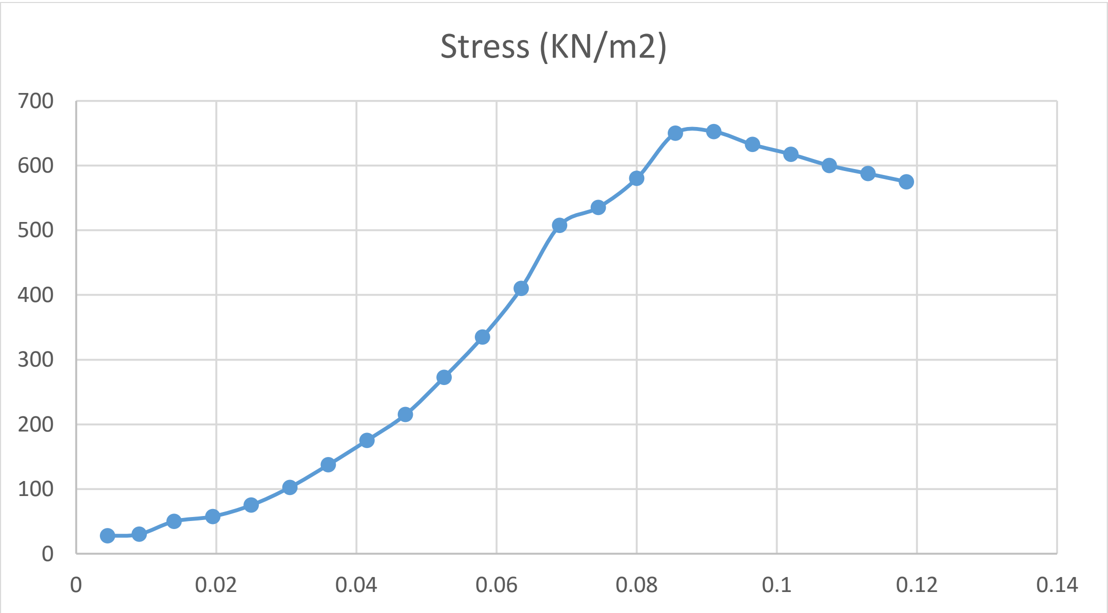
Appendix B: Results

Filled Cube with aggregate:

Cube No.	***Aggregate Size***	***Steel bar Dia.***
1	19 mm	Φ.08
2	9.5 mm	Φ.08
3	9.5 mm	Φ.08
4	9.5 mm	Φ.08
5	19 mm	Φ.08
6	19 mm	Φ.08
7	3 cm	Φ.08
8	19.5	Φ.12
9	3 cm	Φ.12
10	19mm	Φ.06
11	3 cm	Φ.06
12	19 mm	Φ.10
13	3cm	Φ.10

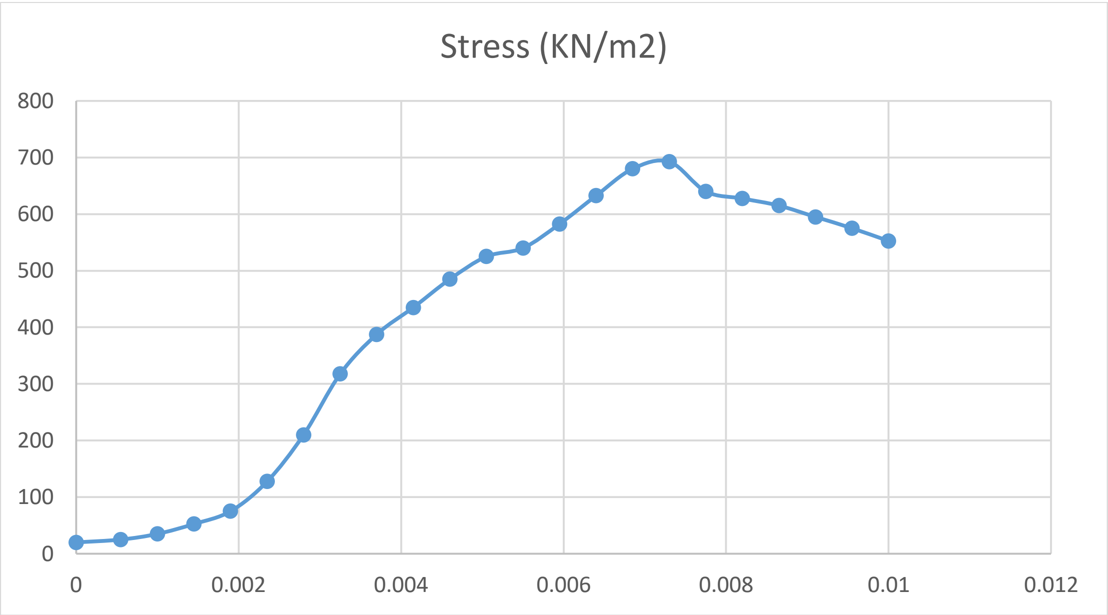
Cube 1:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.6	0	0	15
1.1	0.9	0.0045	27.5
1.2	1.8	0.009	30
2	2.8	0.014	50
2.3	3.9	0.0195	57.5
3	5	0.025	75
4.1	6.1	0.0305	102.5
5.5	7.2	0.036	137.5
7	8.3	0.0415	175
8.6	9.4	0.047	215
10.9	10.5	0.0525	272.5
13.4	11.6	0.058	335
16.4	12.7	0.0635	410
20.3	13.8	0.069	507.5
21.4	14.9	0.0745	535
23.2	16	0.08	580
26	17.1	0.0855	650
26.1	18.2	0.091	652.5
25.3	19.3	0.0965	632.5
24.7	20.4	0.102	617.5
24	21.5	0.1075	600
23.5	22.6	0.113	587.5
23	23.7	0.1185	575



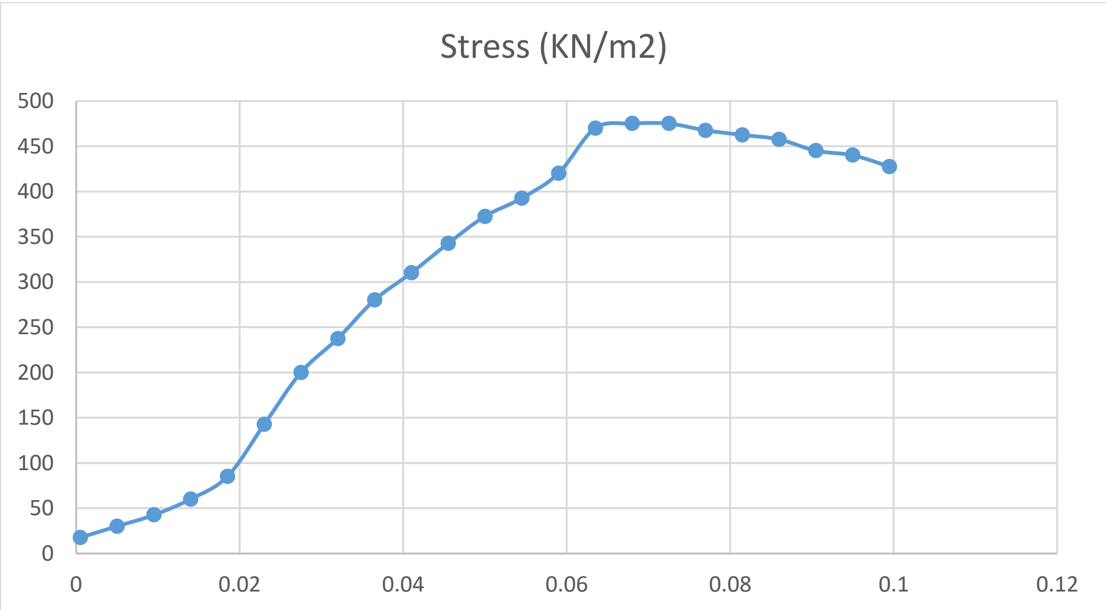
Cube 2:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.8	0	0	20
1	0.11	0.00055	25
1.4	0.2	0.001	35
2.1	0.29	0.00145	52.5
3	0.38	0.0019	75
5.1	0.47	0.00235	127.5
8.4	0.56	0.0028	210
12.7	0.65	0.00325	317.5
15.5	0.74	0.0037	387.5
17.4	0.83	0.00415	435
19.4	0.92	0.0046	485
21	1.01	0.00505	525
21.6	1.1	0.0055	540
23.3	1.19	0.00595	582.5
25.3	1.28	0.0064	632.5
27.2	1.37	0.00685	680
27.7	1.46	0.0073	692.5
25.6	1.55	0.00775	640
25.1	1.64	0.0082	627.5
24.6	1.73	0.00865	615
23.8	1.82	0.0091	595
23	1.91	0.00955	575
22.1	2	0.01	552.5



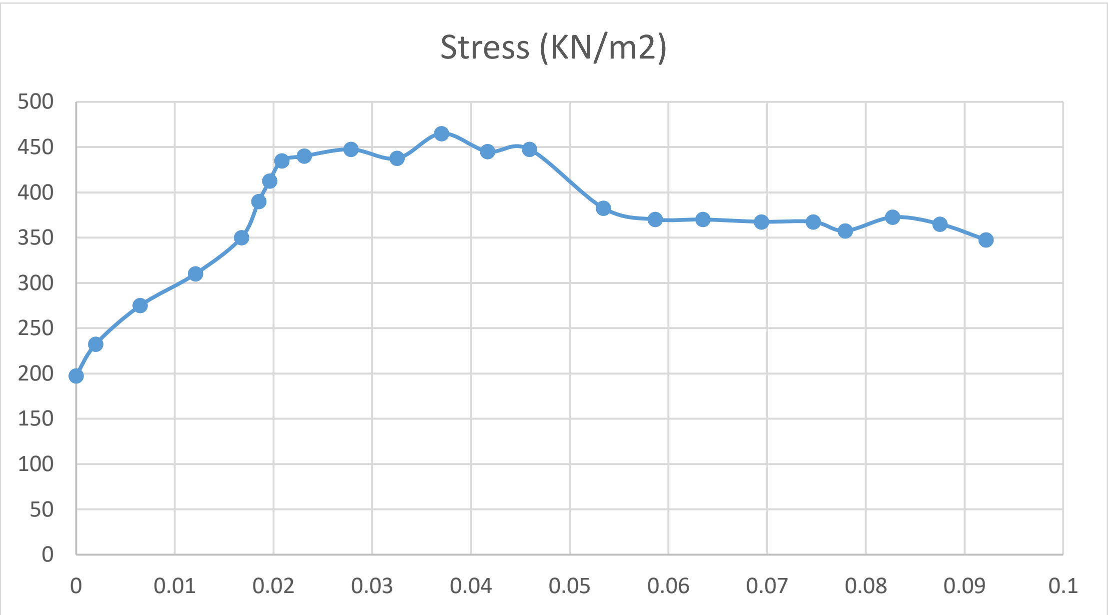
Cube 3:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.7	0.1	0.0005	17.5
1.2	1	0.005	30
1.7	1.9	0.0095	42.5
2.4	2.8	0.014	60
3.4	3.7	0.0185	85
5.7	4.6	0.023	142.5
8	5.5	0.0275	200
9.5	6.4	0.032	237.5
11.2	7.3	0.0365	280
12.4	8.2	0.041	310
13.7	9.1	0.0455	342.5
14.9	10	0.05	372.5
15.7	10.9	0.0545	392.5
16.8	11.8	0.059	420
18.8	12.7	0.0635	470
19	13.6	0.068	475
19	14.5	0.0725	475
18.7	15.4	0.077	467.5
18.5	16.3	0.0815	462.5
18.3	17.2	0.086	457.5
17.8	18.1	0.0905	445
17.6	19	0.095	440
17.1	19.9	0.0995	427.5



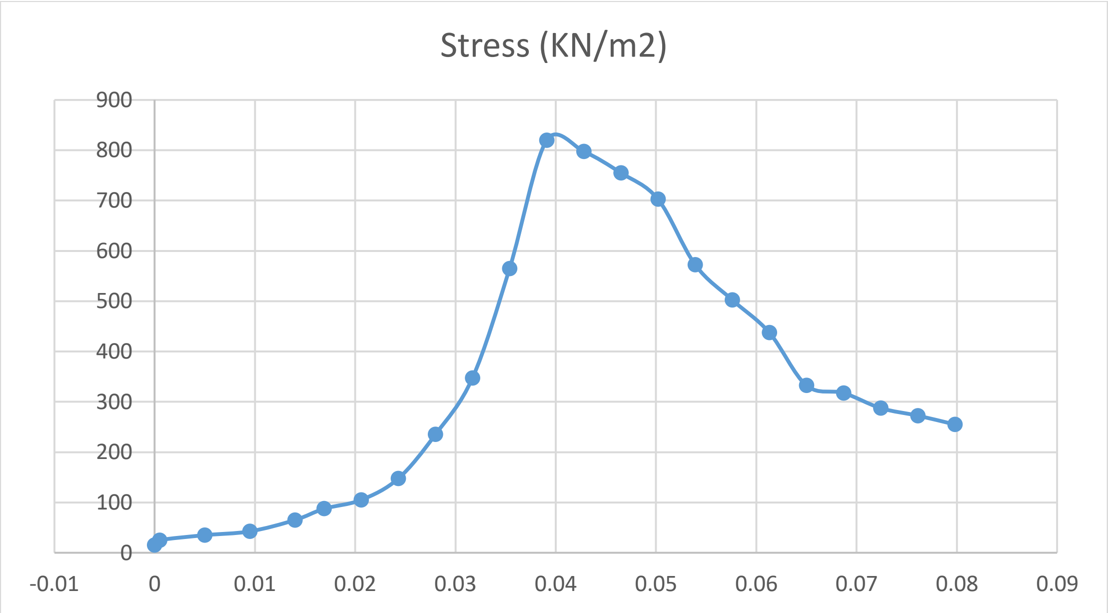
Cube 4:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
7.9	0	0	197.5
9.3	0.4	0.002	232.5
11	1.3	0.0065	275
12.4	2.42	0.0121	310
14	3.35	0.01675	350
15.6	3.7	0.0185	390
16.5	3.92	0.0196	412.5
17.4	4.17	0.02085	435
17.6	4.62	0.0231	440
17.9	5.57	0.02785	447.5
17.5	6.505	0.032525	437.5
18.6	7.405	0.037025	465
17.8	8.335	0.041675	445
17.9	9.185	0.045925	447.5
15.3	10.685	0.053425	382.5
14.8	11.735	0.058675	370
14.8	12.7	0.0635	370
14.7	13.885	0.069425	367.5
14.7	14.935	0.074675	367.5
14.3	15.585	0.077925	357.5
14.9	16.545	0.082725	372.5
14.6	17.505	0.087525	365
13.9	18.435	0.092175	347.5



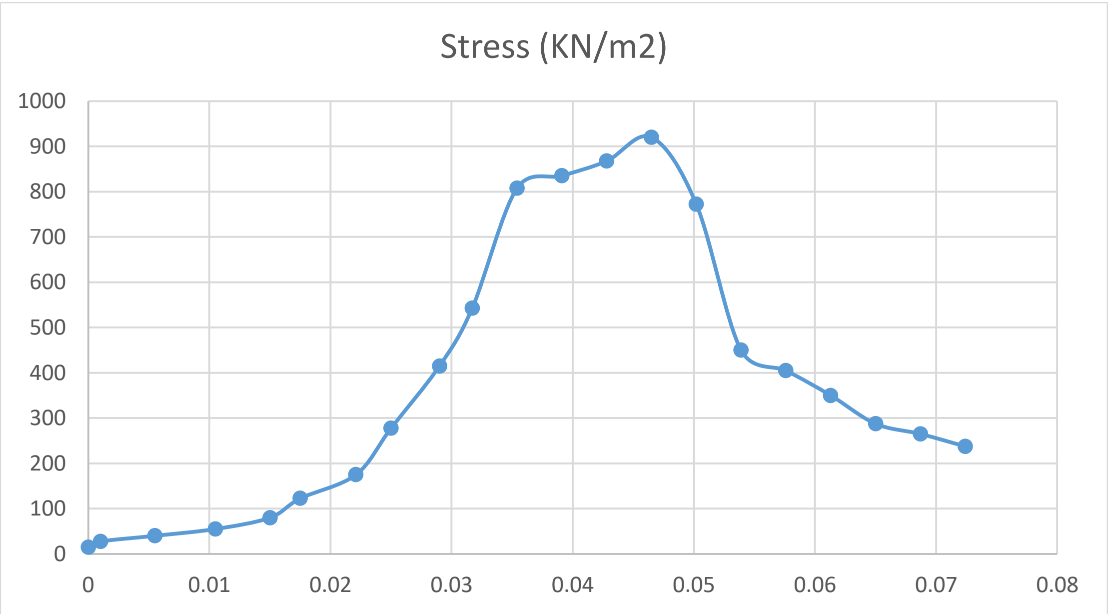
Cube 5:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.6	0	0	15
1	0.1	0.0005	25
1.4	1	0.005	35
1.7	1.9	0.0095	42.5
2.6	2.8	0.014	65
3.5	3.38	0.0169	87.5
4.2	4.12	0.0206	105
5.9	4.86	0.0243	147.5
9.4	5.6	0.028	235
13.9	6.34	0.0317	347.5
22.6	7.08	0.0354	565
32.8	7.82	0.0391	820
31.9	8.56	0.0428	797.5
30.2	9.3	0.0465	755
28.1	10.04	0.0502	702.5
22.9	10.78	0.0539	572.5
20.1	11.52	0.0576	502.5
17.5	12.26	0.0613	437.5
13.3	13	0.065	332.5
12.7	13.74	0.0687	317.5
11.5	14.48	0.0724	287.5
10.9	15.22	0.0761	272.5
10.2	15.96	0.0798	255



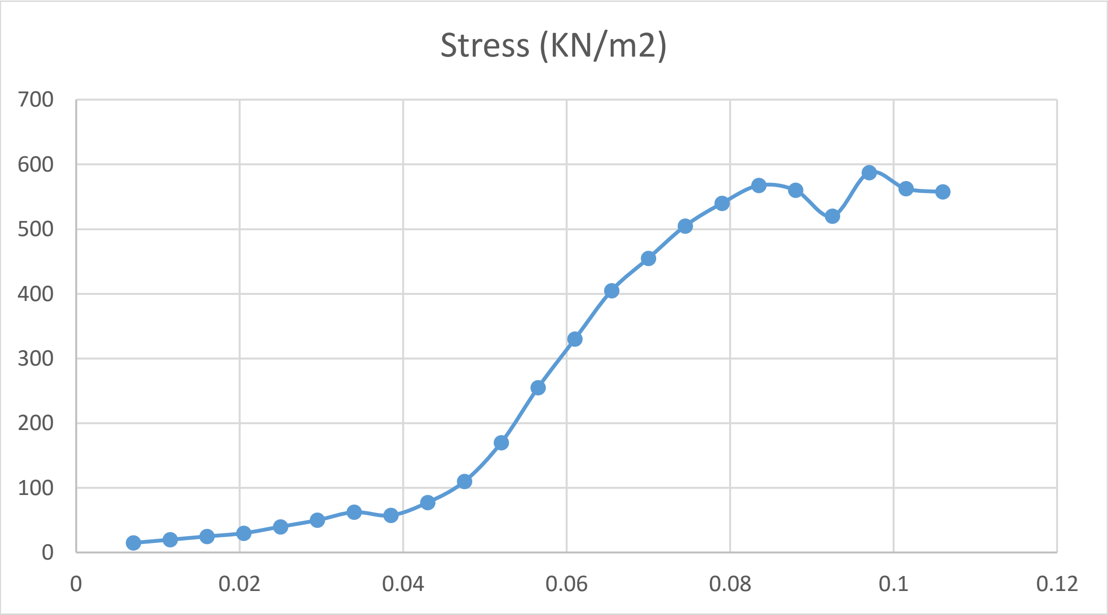
Cube 6:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.6	0	0	15
1.1	0.2	0.001	27.5
1.6	1.1	0.0055	40
2.2	2.1	0.0105	55
3.2	3	0.015	80
4.9	3.5	0.0175	122.5
7	4.42	0.0221	175
11.1	5	0.025	277.5
16.6	5.8	0.029	415
21.7	6.34	0.0317	542.5
32.3	7.08	0.0354	807.5
33.4	7.82	0.0391	835
34.7	8.56	0.0428	867.5
36.8	9.3	0.0465	920
30.9	10.04	0.0502	772.5
18	10.78	0.0539	450
16.2	11.52	0.0576	405
14	12.26	0.0613	350
11.5	13	0.065	287.5
10.6	13.74	0.0687	265
9.5	14.48	0.0724	237.5



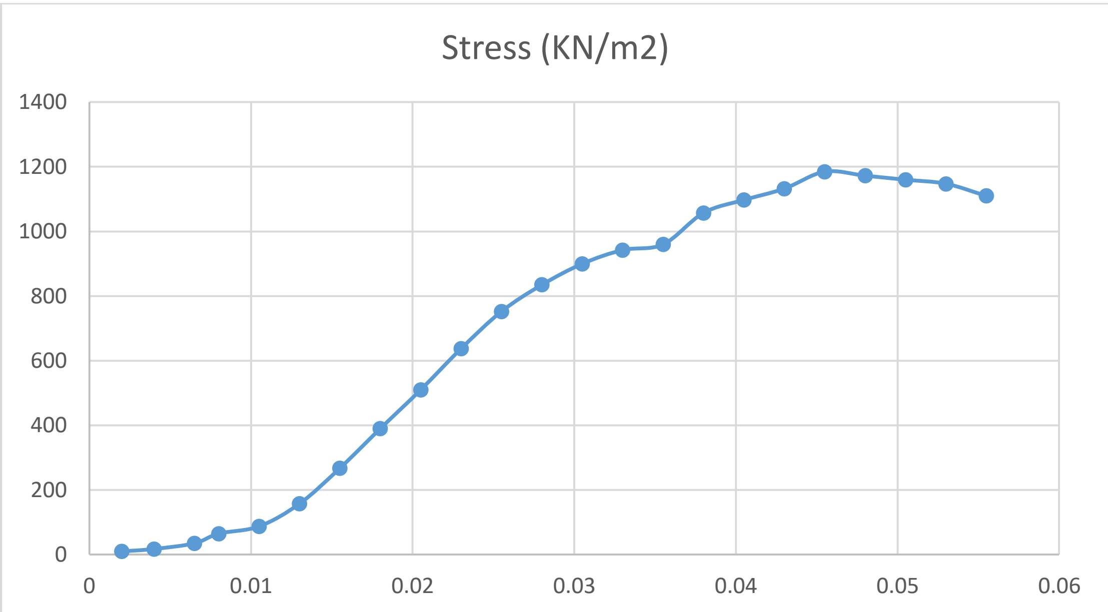
Cube 7:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.4	0.6	0.003	10
0.6	1.4	0.007	15
0.8	2.3	0.0115	20
1	3.2	0.016	25
1.2	4.1	0.0205	30
1.6	5	0.025	40
2	5.9	0.0295	50
2.5	6.8	0.034	62.5
2.3	7.7	0.0385	57.5
3.1	8.6	0.043	77.5
4.4	9.5	0.0475	110
6.8	10.4	0.052	170
10.2	11.3	0.0565	255
13.2	12.2	0.061	330
16.2	13.1	0.0655	405
18.2	14	0.07	455
20.2	14.9	0.0745	505
21.6	15.8	0.079	540
22.7	16.7	0.0835	567.5
22.4	17.6	0.088	560
20.8	18.5	0.0925	520
23.5	19.4	0.097	587.5
22.5	20.3	0.1015	562.5
22.3	21.2	0.106	557.5
21.6	22.1	0.1105	540
19.9	23	0.115	497.5



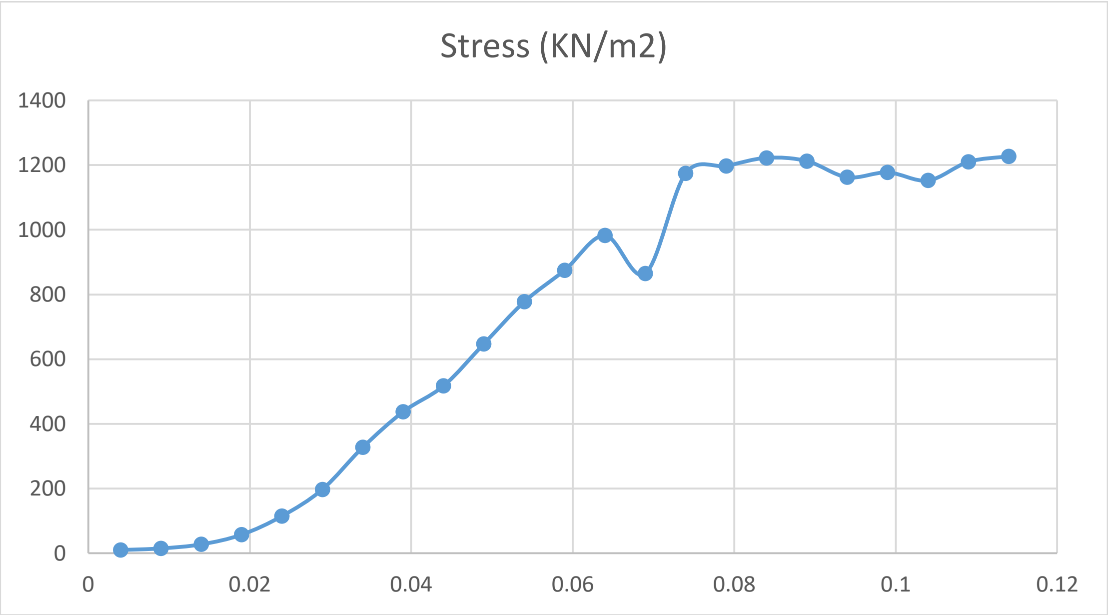
Cube 8:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.4	0.4	0.002	10
0.7	0.8	0.004	17.5
1.4	1.3	0.0065	35
2.6	1.6	0.008	65
3.5	2.1	0.0105	87.5
6.3	2.6	0.013	157.5
10.7	3.1	0.0155	267.5
15.6	3.6	0.018	390
20.4	4.1	0.0205	510
25.5	4.6	0.023	637.5
30.1	5.1	0.0255	752.5
33.4	5.6	0.028	835
36	6.1	0.0305	900
37.7	6.6	0.033	942.5
38.4	7.1	0.0355	960
42.3	7.6	0.038	1057.5
43.9	8.1	0.0405	1097.5
45.3	8.6	0.043	1132.5
47.4	9.1	0.0455	1185
46.9	9.6	0.048	1172.5
46.4	10.1	0.0505	1160
45.9	10.6	0.053	1147.5
44.4	11.1	0.0555	1110
43.6	11.6	0.058	1090
41.9	12.1	0.0605	1047.5
40.3	12.6	0.063	1007.5



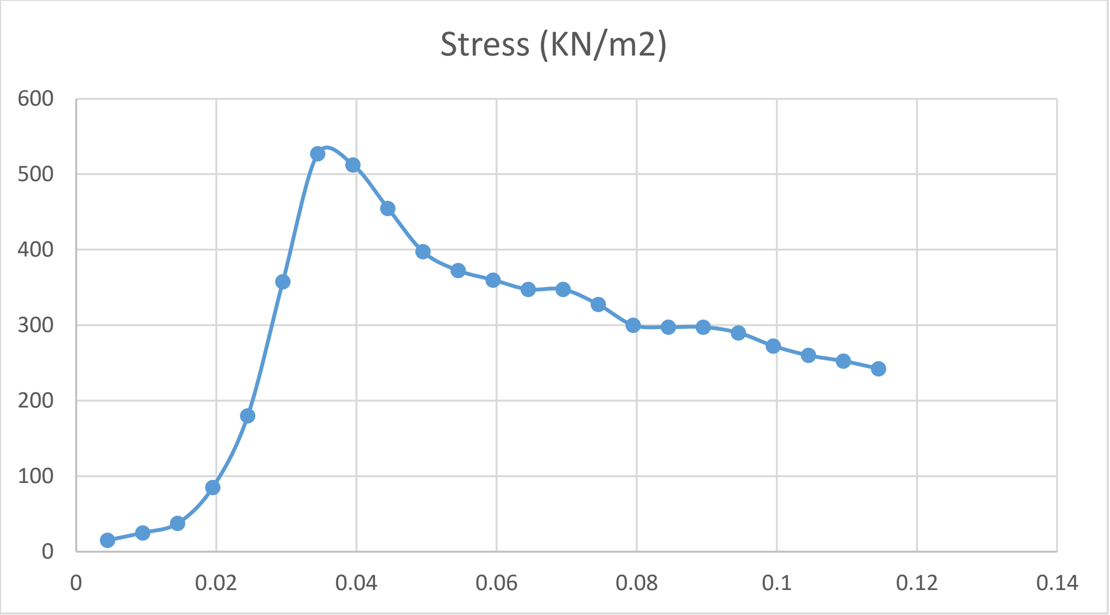
Cube 9:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.4	0.8	0.004	10
0.6	1.8	0.009	15
1.1	2.8	0.014	27.5
2.3	3.8	0.019	57.5
4.6	4.8	0.024	115
7.9	5.8	0.029	197.5
13.1	6.8	0.034	327.5
17.5	7.8	0.039	437.5
20.7	8.8	0.044	517.5
25.9	9.8	0.049	647.5
31.1	10.8	0.054	777.5
35	11.8	0.059	875
39.3	12.8	0.064	982.5
34.6	13.8	0.069	865
47	14.8	0.074	1175
47.9	15.8	0.079	1197.5
48.9	16.8	0.084	1222.5
48.5	17.8	0.089	1212.5
46.5	18.8	0.094	1162.5
47.1	19.8	0.099	1177.5
46.1	20.8	0.104	1152.5
48.4	21.8	0.109	1210
49.1	22.8	0.114	1227.5
49.6	23.8	0.119	1240
50.4	24.8	0.124	1260
51.3	25.8	0.129	1282.5
53	26.8	0.134	1325
54.3	27.8	0.139	1357.5



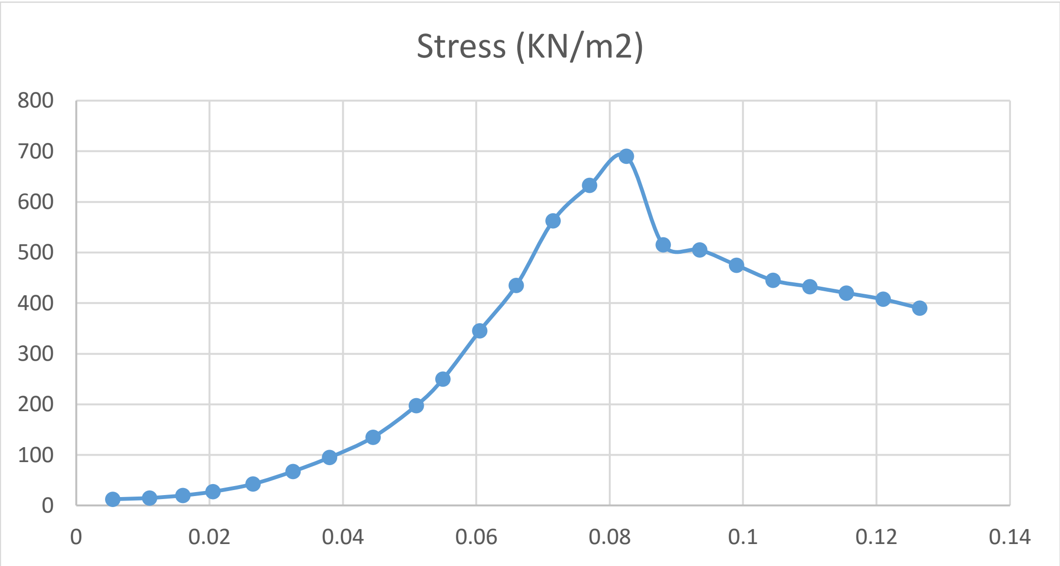
Cube 10:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.6	0.9	0.0045	15
1	1.9	0.0095	25
1.5	2.9	0.0145	37.5
3.4	3.9	0.0195	85
7.2	4.9	0.0245	180
14.3	5.9	0.0295	357.5
21.1	6.9	0.0345	527.5
20.5	7.9	0.0395	512.5
18.2	8.9	0.0445	455
15.9	9.9	0.0495	397.5
14.9	10.9	0.0545	372.5
14.4	11.9	0.0595	360
13.9	12.9	0.0645	347.5
13.9	13.9	0.0695	347.5
13.1	14.9	0.0745	327.5
12	15.9	0.0795	300
11.9	16.9	0.0845	297.5
11.9	17.9	0.0895	297.5
11.6	18.9	0.0945	290
10.9	19.9	0.0995	272.5
10.4	20.9	0.1045	260
10.1	21.9	0.1095	252.5
9.7	22.9	0.1145	242.5



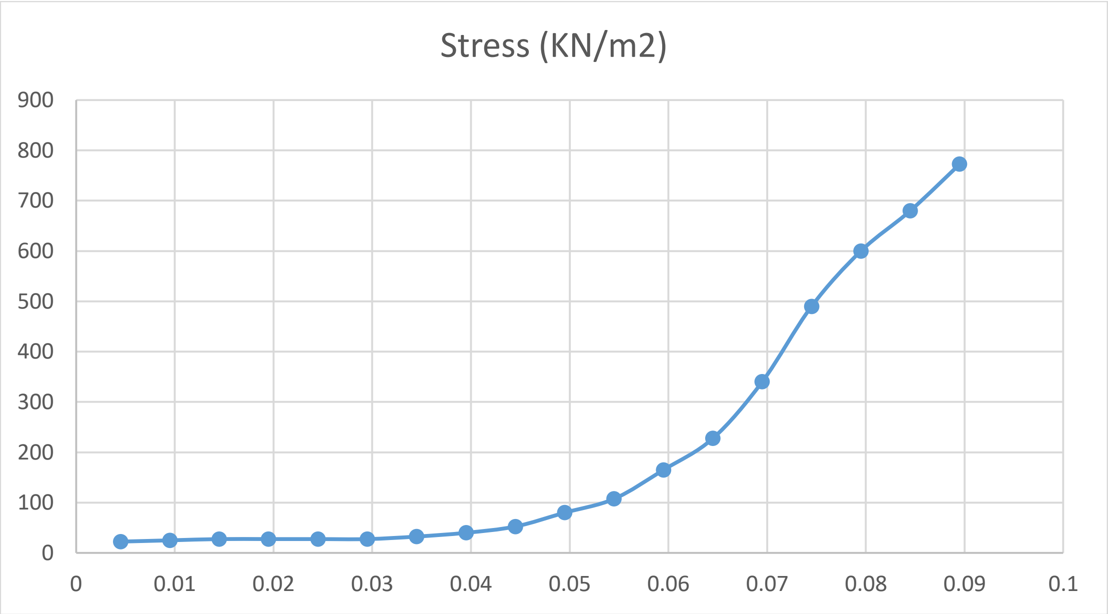
Cube 11:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.5	1.1	0.0055	12.5
0.6	2.2	0.011	15
0.8	3.2	0.016	20
1.1	4.1	0.0205	27.5
1.7	5.3	0.0265	42.5
2.7	6.5	0.0325	67.5
3.8	7.6	0.038	95
5.4	8.9	0.0445	135
7.9	10.2	0.051	197.5
10	11	0.055	250
13.8	12.1	0.0605	345
17.4	13.2	0.066	435
22.5	14.3	0.0715	562.5
25.3	15.4	0.077	632.5
27.6	16.5	0.0825	690
20.6	17.6	0.088	515
20.2	18.7	0.0935	505
19	19.8	0.099	475
17.8	20.9	0.1045	445
17.3	22	0.11	432.5
16.8	23.1	0.1155	420
16.3	24.2	0.121	407.5
15.6	25.3	0.1265	390
15.4	26.4	0.132	385
15.5	27.5	0.1375	387.5
16.4	28.6	0.143	410
15.9	29.7	0.1485	397.5
14.7	30.8	0.154	367.5
13.3	31.9	0.1595	332.5



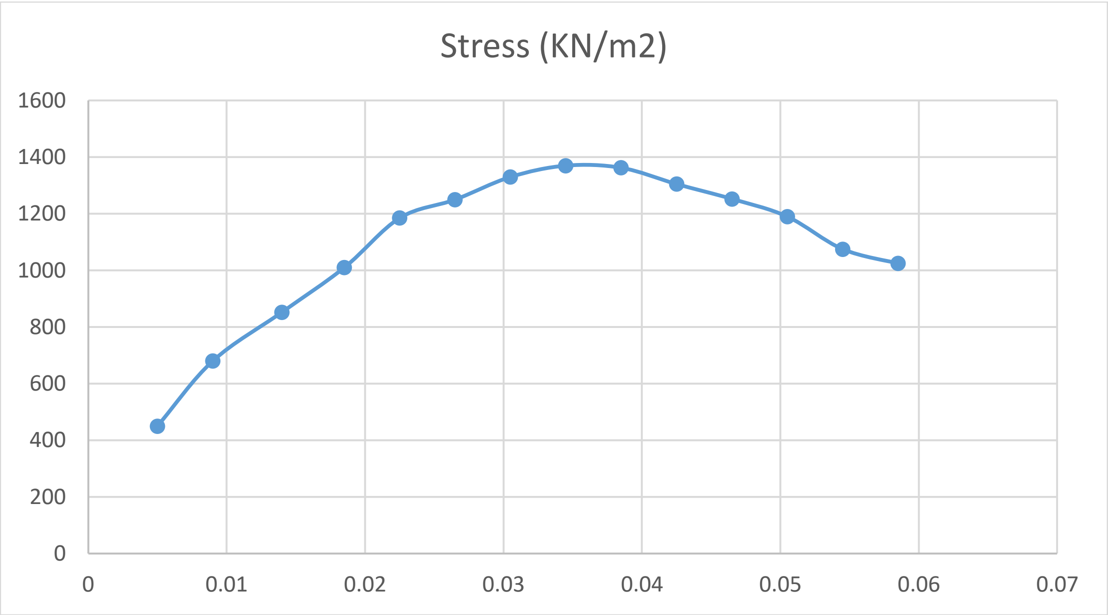
Cube 12:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
0.9	0.9	0.0045	22.5
1	1.9	0.0095	25
1.1	2.9	0.0145	27.5
1.1	3.9	0.0195	27.5
1.1	4.9	0.0245	27.5
1.1	5.9	0.0295	27.5
1.3	6.9	0.0345	32.5
1.6	7.9	0.0395	40
2.1	8.9	0.0445	52.5
3.2	9.9	0.0495	80
4.3	10.9	0.0545	107.5
6.6	11.9	0.0595	165
9.1	12.9	0.0645	227.5
13.6	13.9	0.0695	340
19.6	14.9	0.0745	490
24	15.9	0.0795	600
27.2	16.9	0.0845	680
30.9	17.9	0.0895	772.5



Cube 13:

F (kN)	Def(mm)	Strain	Stress (KN/m2)
18	1	0.005	450
27.2	1.8	0.009	680
34.1	2.8	0.014	852.5
40.4	3.7	0.0185	1010
47.4	4.5	0.0225	1185
50	5.3	0.0265	1250
53.2	6.1	0.0305	1330
54.8	6.9	0.0345	1370
54.5	7.7	0.0385	1362.5
52.2	8.5	0.0425	1305
50.1	9.3	0.0465	1252.5
47.6	10.1	0.0505	1190
43	10.9	0.0545	1075
41	11.7	0.0585	1025



Photos of cubes:


3
9.5 mm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size
9.5 mm


size
19


Size
19
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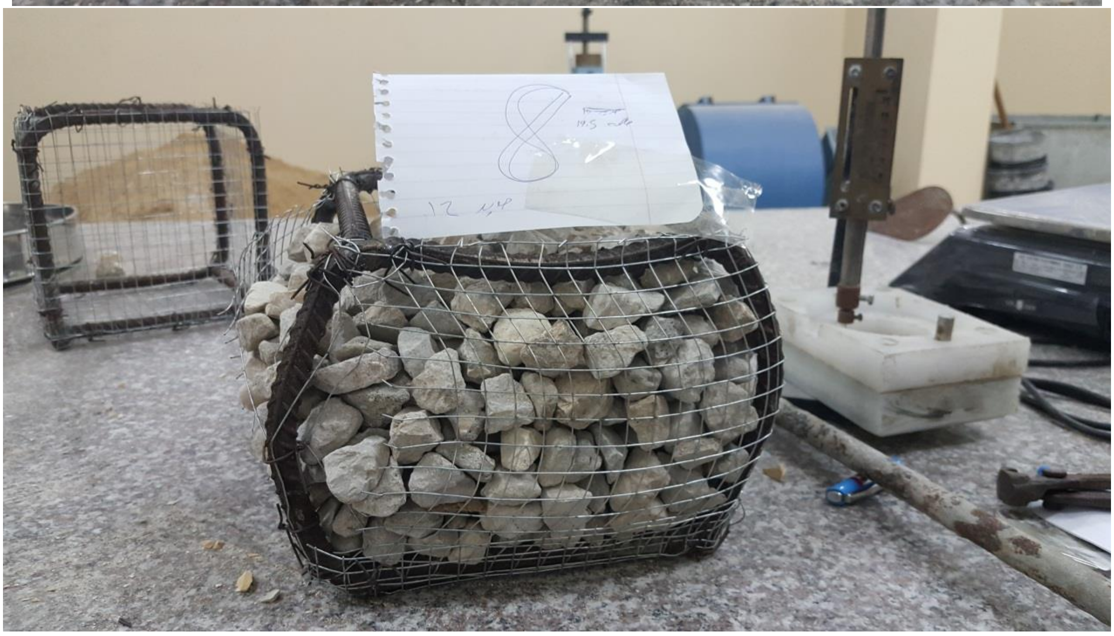
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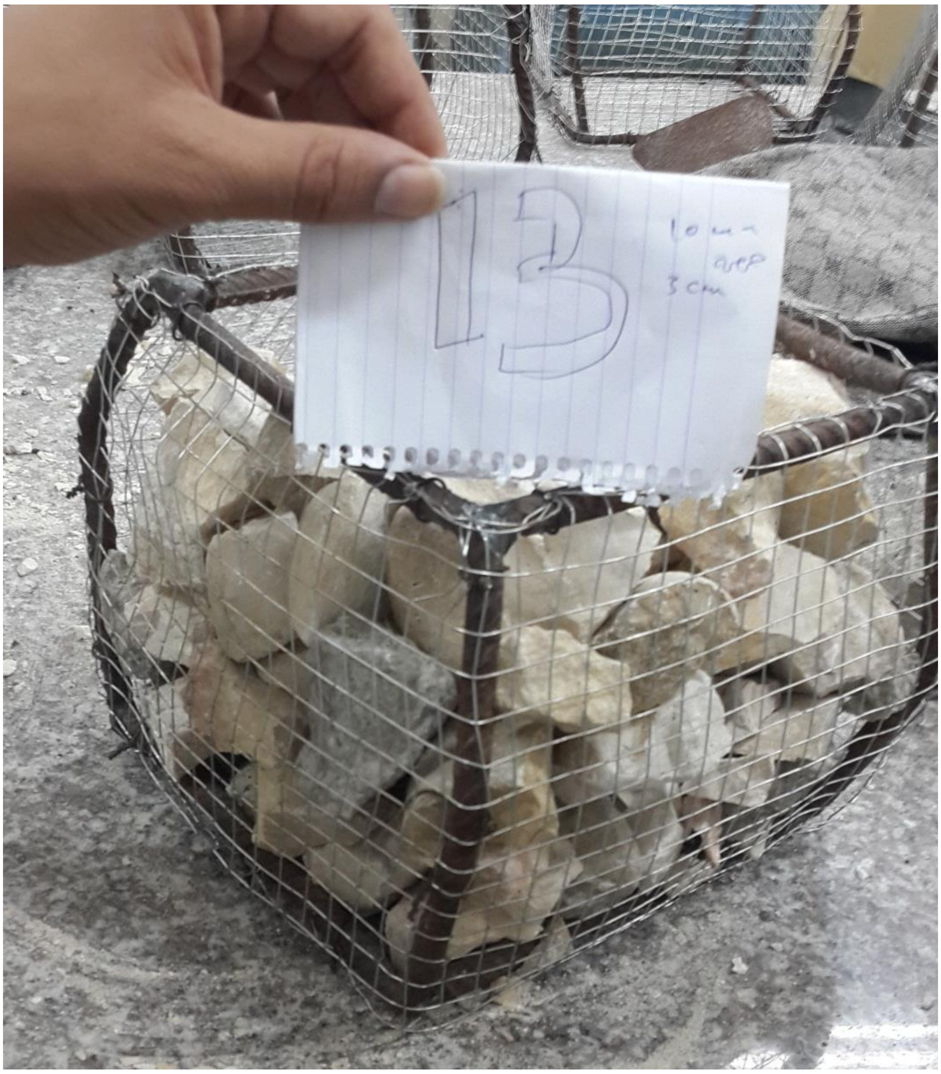
12


13
3cm